SEWAGE AND INDUSTRIAL WASTES

(Formerly Sewage Works Journal)

JOURNAL of the FEDERATION OF SEWAGE AND INDUSTRIAL WASTES ASSOCIATIONS

Special Features

1956 Literature Review, Part I—Research Committee

Analytical Methods—Sewage

T. B. Transmission—Greenberg and Kupka

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Preliminary Studies

MAY, 1957—VOL. 29, No. 5

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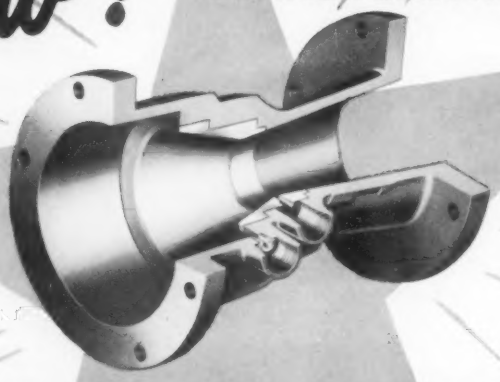

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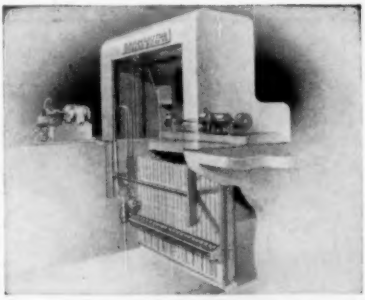

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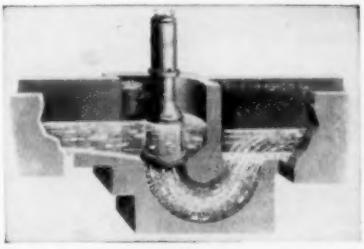

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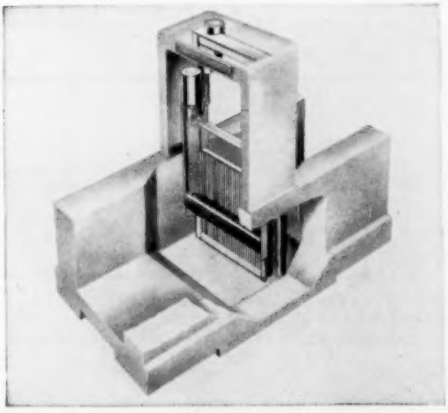

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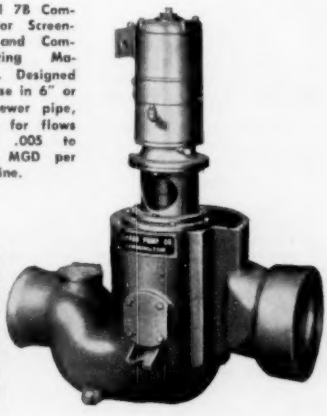

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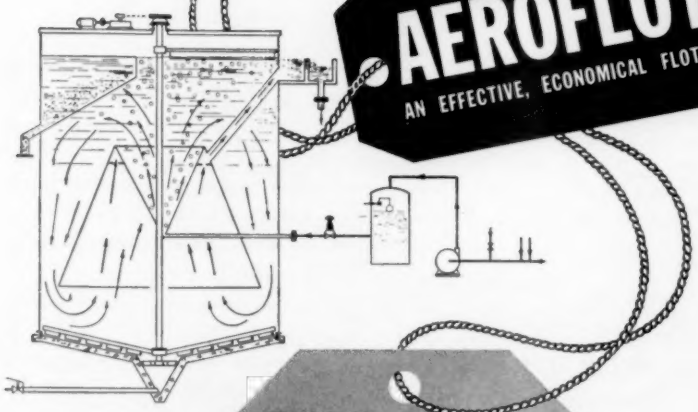

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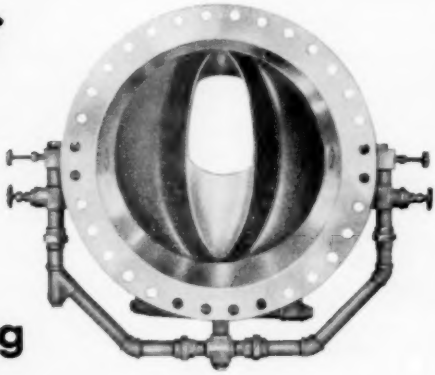

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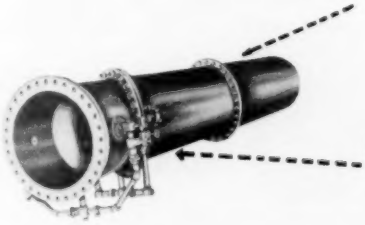

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Maryland-Delaware Water and Sewage Assn.	Commander Hotel Ocean City, Md.	May 22–24, 1957
Sweden (Foreningen For Vattenhygien)	Danish Engineering Society Copenhagen, Denmark	May 31–June 1, 1957
Alabama Water and Sewage Assn.	University of Alabama University, Ala.	June 3–5, 1957
New England Sewage and Industrial Wastes Assn.	Viking Hotel Newport, R. I.	June 6, 1957
New York Sewage and Industrial Wastes Assn.	Whiteface Inn Lake Placid, N. Y.	June 17–18, 1957
Iowa Sewage and Industrial Wastes Assn.	Hotel Kirkwood Des Moines, Iowa	June 19–21, 1957
Ohio Sewage and Industrial Wastes Treatment Conf.	Miami Hotel Dayton, Ohio	June 19–21, 1957
Institute of Sewage Purification	Margate, England	June 25–28, 1957
Central States Sewage and Industrial Wastes Assn.	Sherman Hotel Chicago, Ill.	June 26–28, 1957
Pennsylvania Sewage and Industrial Wastes Assn.	Pennsylvania State College University Park, Pa.	Aug. 28–30, 1957
South Dakota Water and Sewage Works Conference	Sheraton Cataract Hotel Sioux Falls, So. Dak.	Sept. 11–13, 1957

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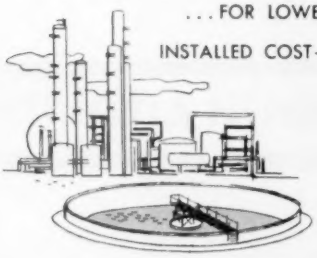

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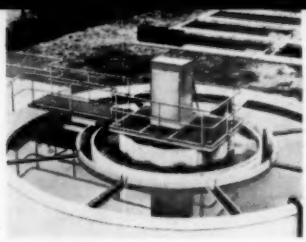

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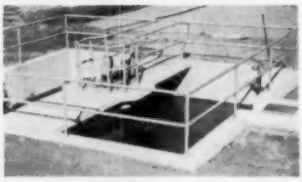

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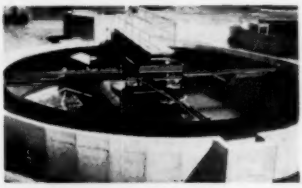

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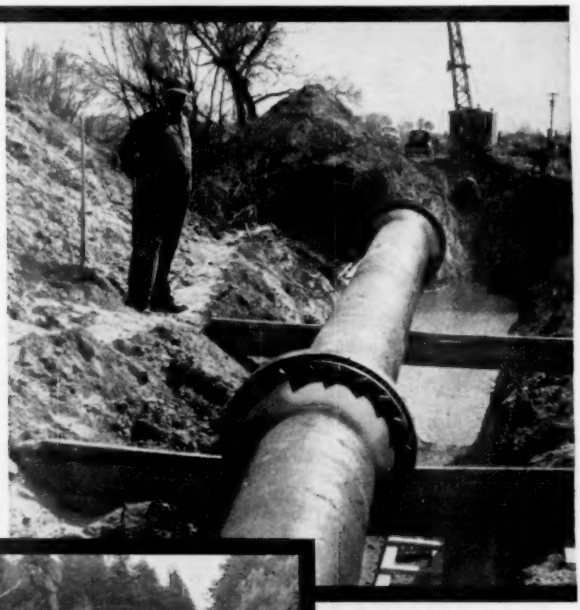

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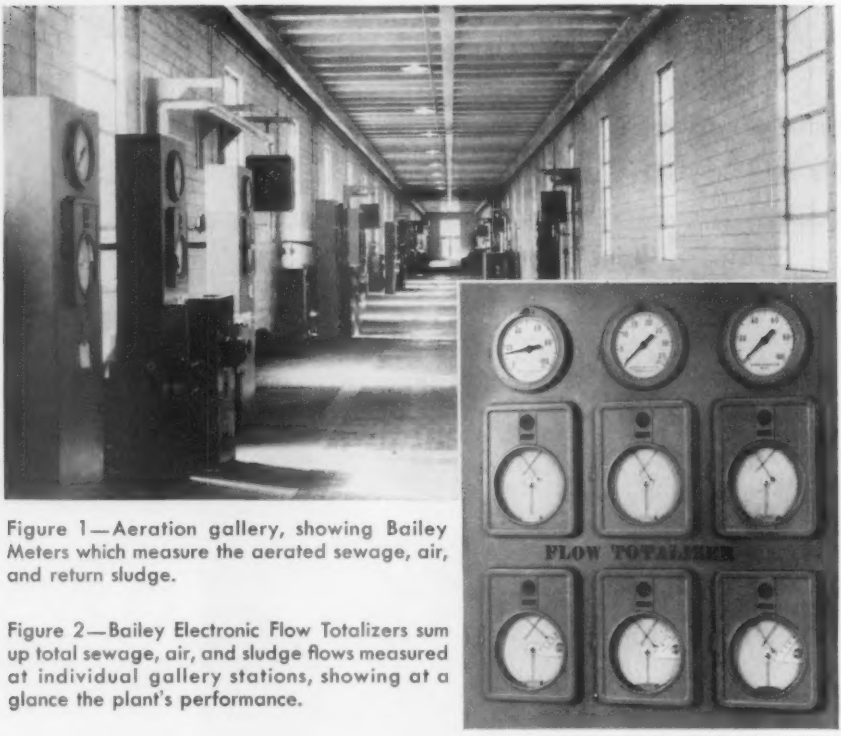

Figure 1—Aeration gallery, showing Bailey Meters which measure the aerated sewage, air, and return sludge.

Figure 2—Bailey Electronic Flow Totalizers sum up total sewage, air, and sludge flows measured at individual gallery stations, showing at a glance the plant's performance.

Havens & Emerson—Consulting Engineers

FLOW TOTALIZATION – at Southerly Sewage Treatment Plant

Instantaneous plant performance and operating trends are continuously available to supervisors and operators through Bailey's Electronic Flow Totalizer.

The new 32 MGD addition to the Southerly Sewage Treatment Plant, Cleveland, Ohio is equipped with Bailey Flow Meters, Integrators, Indicators, and Recorders.

Complete instrumentation and automatic controls for sewage and industrial waste treatment plants are engineered and manufactured by Bailey to meet the most rigid requirements of any size plant.

If you are planning new construction, a Bailey Application Engineer will be pleased to help you lay out your instrument and control requirements. MU-26

WATER & WASTE TREATMENT DIVISION

BAILEY METER COMPANY

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In Canada—Bailey Meter Company Limited, Montreal

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Specify IOWA for every job

Iowa's complete line of valves for treatment plants assures you of efficient operation, low maintenance cost, and replacement parts when needed in years to come.

IOWA CHECK VALVES—Swing gate type for use in either horizontal or vertical pipe lines. Bronze trimmed throughout. Stainless steel hinge pins. Leather or rubber faced gates, or solid bronze, as desired—aluminum gates available for air service.

IOWA MEDIUM AND LOW PRESSURE VALVES—either non-rising stem or outside screw and yoke types. Designed as carefully as those conforming to A.W.W.A. specifications but with lighter construction for lower pressures.

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IOWA FLAP VALVES—all iron; can be furnished with bronze hinge bolts or fully bronze mounted—including bronze bolts, flap ring and seat ring—when required.

CLOW HYDROSTATIC RELIEF VALVES — commonly used in bottom of concrete tanks to prevent ground water from floating the tank. Close-grained cast iron body and lid; lead seat ring and lid ring. Cast iron grate in bottom prevents foreign matter from entering tank.

IOWA PLUG DRAIN VALVES—either rising or non-rising stem type. High strength cast iron bodies; bronze stem, operating nut, disc ring and seat ring; rustproof steel bolts and nuts. Handwheels, extension stems, plain or indicating floor stands if required.

IOWA SLUICE GATES—can be used in lines having both seating and unseating pressures. High strength cast iron, bronze mounted, with solid bronze adjustable wedges. Can be equipped with cylinder or motor unit for automatic operation.

IOWA SHEAR GATES—either all iron or iron, bronze mounted. Gate-seating wedges bolted on, permitting replacement without replacing frame.

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IOWA VALVE COMPANY

A Subsidiary of James B. Clow & Sons

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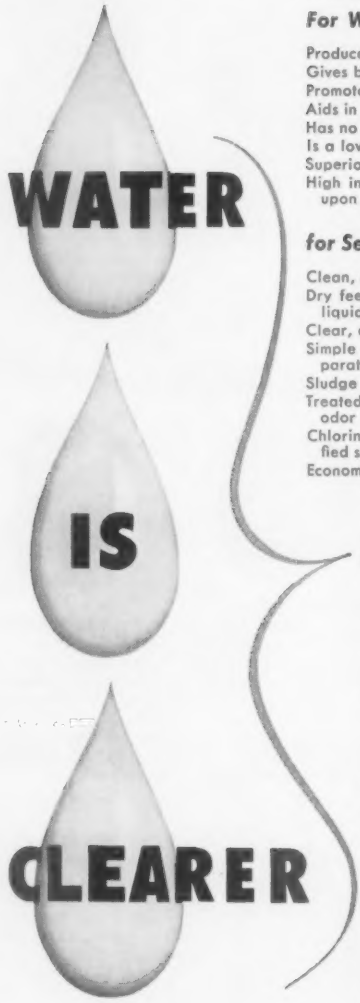

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Produces crystal-clear water
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Is a low-cost coagulant
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Simple application. Requires only low-cost feeding apparatus and minimum attention
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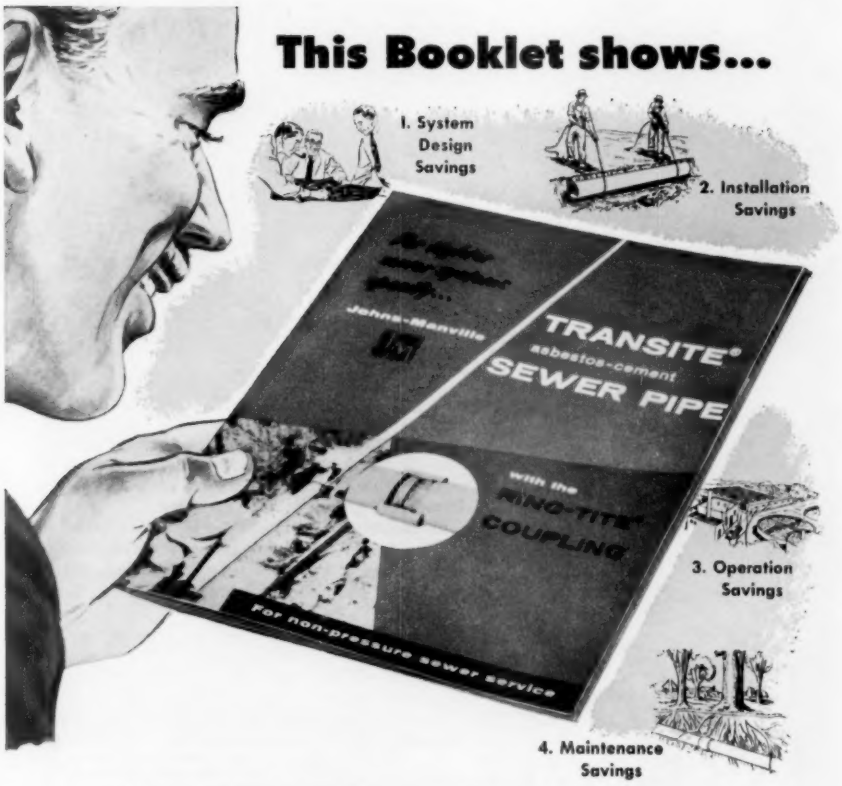

...how Transite Sewer Pipe saves in **4** important ways

Selecting the right pipe material for a new sewage system—or for additions to an existing one—is a problem of major importance to *all* concerned in influencing a choice. *And* it can be solved to *the complete satisfaction of both installer and user* with economies in each of these stages—(1) system design (2) installation (3) operation and (4) maintenance.

Engineers thinking in long-range terms of thoroughly proved sewer main performance . . . contractors interested in serving community needs at new lows in installed cost—both should know Transite® asbestos-cement Pipe and Ring-Tite® Coupling. Here is a new booklet that tells how Transite Pipe reduces infiltration, keeps out roots; maintains high flow capacity; speeds installation; permits designing the system for savings. Write for Booklet TR-165A, Johns-Manville, Box 14, New York 16, N. Y.; In Canada, Port Credit, Ont.

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WITH THE **RING-TITE** COUPLING

sewage treatment plants *can* be good neighbors, too . .

Can sewage treatment plants be good neighbors? Yes—if the housekeeping is good, and all sewage solids are reduced to ash immediately in Nichols Herreshoff Multiple Hearth furnaces.

As illustrated here, the necessity of building sewage treatment plants adjacent to residential areas is becoming more prevalent. These plants must not offend their neighbors with odors, smoke or fly ash.

Modern Nichols Herreshoff furnaces convert by high temperature combustion all putrescible solids of sewage—grits, grease, screenings and sludge —to clean, innocuous gases and inert ash.

Yes, sewage treatment plants can be good neighbors.

Illustrated here are two views of the West New York, N. J., sewage treatment plant, Nichols Herreshoff equipped.

CONSULTING ENGINEER: Frank J. Oleri, West New York, N. J.

Nichols Herreshoff

Multiple Hearth Dryer-Incinerators

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for pumping domestic and industrial wastes...

This Shone ejector has been in operation for 68 trouble-free years—in the Auditorium Hotel (Roosevelt College), Chicago, Illinois.

YEOMANS pneumatic ejectors cut service costs because

THERE'S NOTHING TO WEAR OUT

- NO ROTATING PUMP PARTS
- NO AIRTIGHT FLOATS
- NO HIGH-SPEED SHAFTS OR BEARINGS

With Yeomans pneumatic ejectors, maintenance costs are 50% to 75% lower than with the best centrifugal pumps. The secret? Simplicity of design. Yeomans pneumatic ejectors are built to give you decades of trouble-free service—in fact, they will outlast your system.

They're recommended for low gallonages. Even the smallest Yeomans ejector will pass solids up to the size of the inlet and discharge valves . . . minimum of four inches. No danger of clogging.

They're safer, and completely sanitary. Fully enclosed, hermetically sealed. Dangerous hydrogen sulphide gas is never released.

Yeomans manufactures both centrifugal pumps and pneumatic ejectors, but recommends the ejector where extreme dependability is required. Among the seven models and more than 100 sizes there is a pneumatic ejector that will exactly fill your needs.

Manufacturers of: pumps for drainage • sewage • condensation return • water supply and circulation • equipment for treatment of domestic and industrial wastes.

YEOMANS

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This AMVIT* SEWER LINE is a life line carrying industrial wastes to safe disposal

Carborundum Metals Company
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Engineers and Builders
The H. K. Ferguson Company

This is the last time you'll see that length of pipe going into the ditch. Yet it will serve a new industrial plant for many years.

That sewer line will carry thousands of gallons of diluted acids, oils, alkali solutions and other waste material from Carborundum Metals new plant to a nearby treatment plant. Here the already diluted waste materials are made completely neutral and harmless to plant, animal and fish life. This line is one of the important life lines of that factory.

The Amvit joint was specified for this job because like the clay pipe it is unharmed by underground service.

A true mechanical joint, Amvit is made from plasticized resins of polyvinyl chloride. Thousands of feet of Amvit Jointed Clay Pipe have been installed on industrial waste disposal lines such as this.

Amvit Jointed Clay Pipe, in sizes 4" through 24", together with all fittings is available for immediate delivery in Northeast and Central States.

For more information, write or call American Vitrified Products Company, National City Bank Building, Cleveland, Ohio, or our office nearest you.

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The Amvit Joint is made of a plastic material with rubber-like characteristics. Like the pipe, the joint will withstand the most severe underground conditions. Amvit Joint is furnished on all fittings.

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Installations in hundreds of cities, in over 30 states, testify to the QUALITY and ECONOMY of

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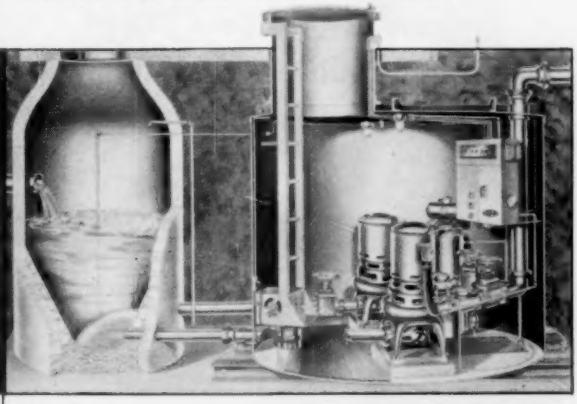
FACTORY-BUILT SEWAGE LIFT STATIONS!

Smith & Loveless
BUILDS
11
LIFT STATIONS
FOR
BENTON TOWNSHIP MICHIGAN



- ONE 8′ dia., 350 GPM pumps, magnetic flowmeter
- ONE 8′ dia., 500 GPM pumps
- ONE 7′ dia., 200 GPM pumps
- ONE 8′ dia., 350 GPM pumps
- ONE 8′ dia., 150 GPM pumps, magnetic flowmeter
- TWO 7′ dia., 250 GPM pumps
- TWO 7′ dia., 150 GPM pumps
- ONE 7′ dia., 100 GPM pumps
- ONE 9′6″ dia., 600 GPM pumps

Benton Township had limited funds available, but the Township had immediate need for a modern sewage collection system. To the consulting engineers, R. W. Petrie & Associates of Benton Harbor, who specified factory-built lift stations, the problem was no different from that encountered by numerous other Michigan communities where 35 Smith & Loveless factory-built lift stations are in operation. The successful contractor, Pearson Construction Company of Benton Harbor, through our sales representatives, DuBois-Cooper Associates, awarded Smith & Loveless the order for the pumping stations.

The Smith & Loveless Underground Sewage Lift Station is a complete FACTORY-BUILT UNIT, shipped READY FOR INSTALLATION . . . It is necessary only to lower it into place, make the piping connections, and it's ready for operation. Regardless of the application or location, you can depend upon Smith & Loveless proven-quality lift stations to CUT COSTS and REDUCE MAINTENANCE TROUBLE — because:

- UNDERGROUND installation eliminates land and building expense
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- Low initial cost, easy maintenance, sustained dependability

A complete line of standard-size lift stations with capacities from 20 GPM to 4500 GPM per pump or ejector. Larger sizes built to order.

For job recommendations, complete specifications and drawings—all part of the latest edition of the 100-page Smith & Loveless lift station Data Manual, write Department 30.

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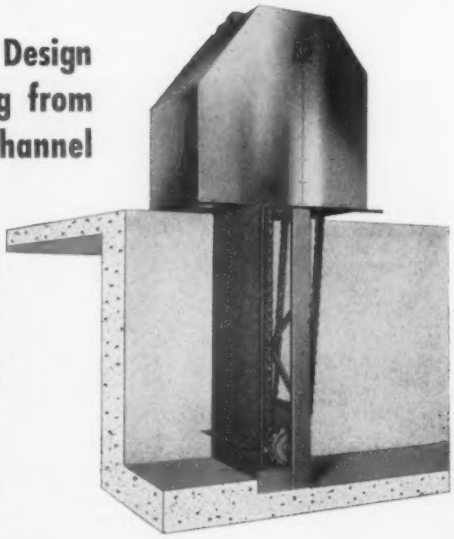
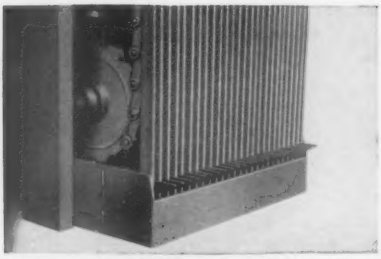
COMPLETELY AUTOMATIC MECHANICALLY CLEANED

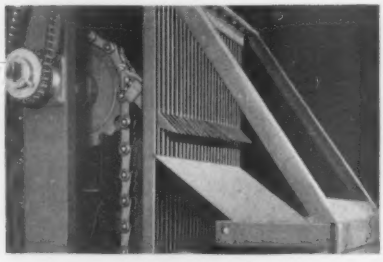
UNIT BAR SCREEN

Exclusive Pivoted Rake Design Assures Positive Raking from Absolute Bottom of Channel





Horizontal position of rake teeth at the beginning of cleaning cycle accomplishes raking from absolute bottom of channel. Gets under and picks up all screenings—does not push them away • Note unobstructed channel approach.



Rake making 45° radial drop to discharge screenings into trough—Note shear pin hub with tool steel shaft and hub inserts for perfect shear action.

THE "AMERICAN" UNIT SCREEN

Completely automatic with a limit switch which stops operation with the rake out of the flow when time control or water level control cycles have been completed • Easily installed as a unit in concrete channels • Total height of unit from mounting floor to motor base is only five feet • The entire above-floor structure is enclosed with stainless steel panels secured by quick opening fasteners to permit easy inspection and access.

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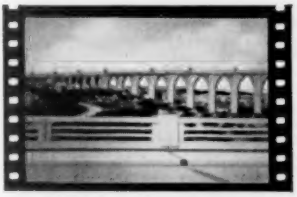

Water transported into Rome by aqueducts.

Concrete Pressure Pipe supplies water for modern industry.

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No matter what your requirements are, installations, *in every case*, are easy with Chapman Standard Sluice Gates. The reasons are soon obvious.

All component parts . . . discs, guides, hooks and wedges . . . in more than 300 available types and sizes are standardized. That means they're interchangeable. Regardless of your specifications, you always get a quick perfect fit. There's nothing hit or miss about it. No expensive, time consuming match-marking. No extensive field alterations. You get a quick, perfect fit *at* lowest possible cost.

Even after installation, your savings never stop. These standardized, interchangeable parts are easily replaced. Your maintenance cost for keeping your sluice gates in excellent working order is low, *the lowest possible.*

This applies to all Chapman Standard Sluice Gates . . . for high or low head, seating or unseating pressures, large or small water areas . . . with manual, hydraulic or electric motor operation. All available in the fastest possible time.

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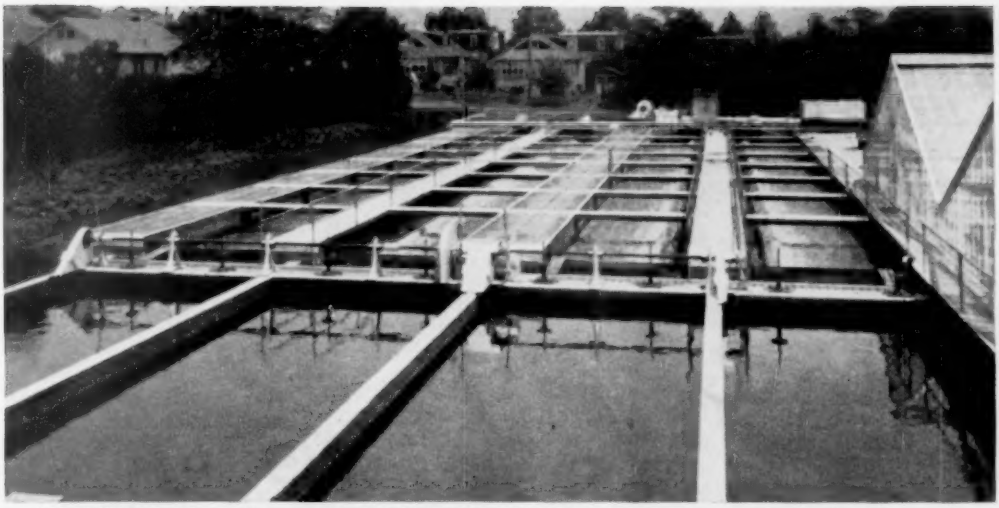
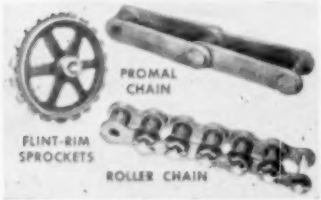
The CHAPMAN Valve Manufacturing Co.

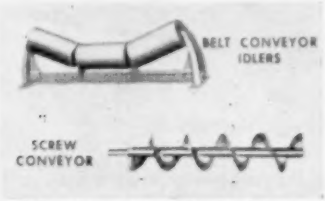
INDIAN ORCHARD, MASSACHUSETTS



FOR 15 YEARS, Link-Belt chain on final tank Straightline Collectors at this activated sludge plant rendered dependable service without replacement, operating 24 hours a day. At other plants, Straightline Collectors have been in operation for a quarter century without replacements. Clearness of effluent may be judged by reflection of drive machinery in final tanks in foreground.



Precision steel roller chain transmits power positively at high or low speeds. Super-strong *Promal chains* and *Flint-Rim sprockets* were developed by Link-Belt.



Industry's most comprehensive *belt-conveyor idler* line features long-lived alignment, effective seals. Smooth, strong helicoid or sectional flights cut *screw conveyor* wear.

Choose from the broadest line of precision *self-aligning ball and roller bearings*, plus water-lubricated *Peak-Cap bearings* that won't accumulate sludge.

To the man who thinks of tomorrow

when specifying today's sanitary engineering requirements

Performance records support the LINK-BELT story

IN supplying your needs in municipal sewage and water treatment or industrial waste treatment, Link-Belt offers three vital "extras" you won't find written into specifications or quotations. The first—durability—is proved in exceptional service records like the plant above. Second is the extensive Link-Belt equipment line—screens, collectors, mixers, conveying and power transmission products—your assurance of impartial recommendations directly determined by your requirements. Third: prompt service, available from 40 Link-Belt district offices.

Your contractor may welcome the information that Link-Belt can supply complete erection service . . . of great convenience to him because of the specialized character of erection work necessary to achieve a well-fitted, complete installation without trouble or delay. Major cost savings, too, result from using Link-Belt's specialized erection crews who can travel anywhere to install Link-Belt water, sewage or waste treatment equipment.

Call your local Link-Belt office for consultation with a sanitary engineering specialist. He will gladly work with your own chemists and consultants.

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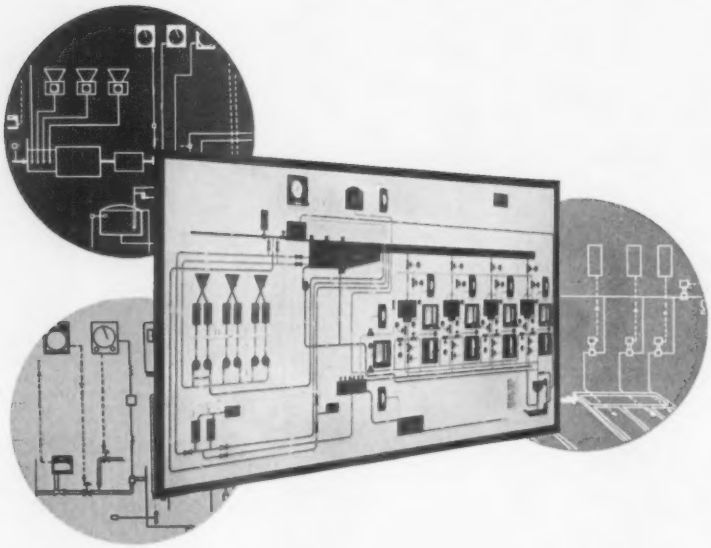

In water, waste, and sewage treatment . . .

A CONTROL SYSTEM IS WHAT YOU MAKE IT

There's more to a control system than just the instruments. First, there has to be a plan that ties them together. Whether you need a simple metering facility, or a complex control network for one-man operation, Fischer & Porter will work with you in formulating such a plan. Drawing upon broad experience in every area of water, waste, and sewage treatment, Fischer & Porter can provide all the equipment necessary to measure, record and control . . . including graphic centralized control panels and automatic data logging systems, chlorinators and chemical feed equipment.

For a small system or a large one, there's much to be gained from this approach. Fischer & Porter alone offers you the benefits of unified responsibility at every step—through analysis, design, manufacture, installation, start-up, and operator training. If you'd like to hear more about this service, contact the Fischer & Porter field engineer serving you . . . or write Fischer & Porter Co., 1157 Fischer Road, Hatboro, Pennsylvania.

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Remember these qualities when you build for the future and specify Clay Pipe—the only pipe with a proof-of-performance *long-term guarantee.*

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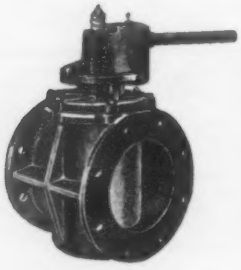
In a DeZurik Valve, the plug is pivoted eccentrically, touching the seat only when the valve is closed. In opening the valve, the plug swings back and away from the seat easily—without sticking, without jamming, without lubrication! The resilient plug facing of a DeZurik Valve seals tight despite solids in the flow—you get dead-tight shut-off on any line!

DeZurik Valves are demonstrating their versatile superiority every day on installations ranging from raw sludge lines and raw sewage lines to gas lines and final effluent lines. On every installation they're proving again and again to be *the* valve in sewage treatment plants.

DeZurik Valves are manufactured in sizes from ½″ thru 20″ and in a wide range of models for manual or remote operation. Representatives in all principal cities. Or for more details, write to



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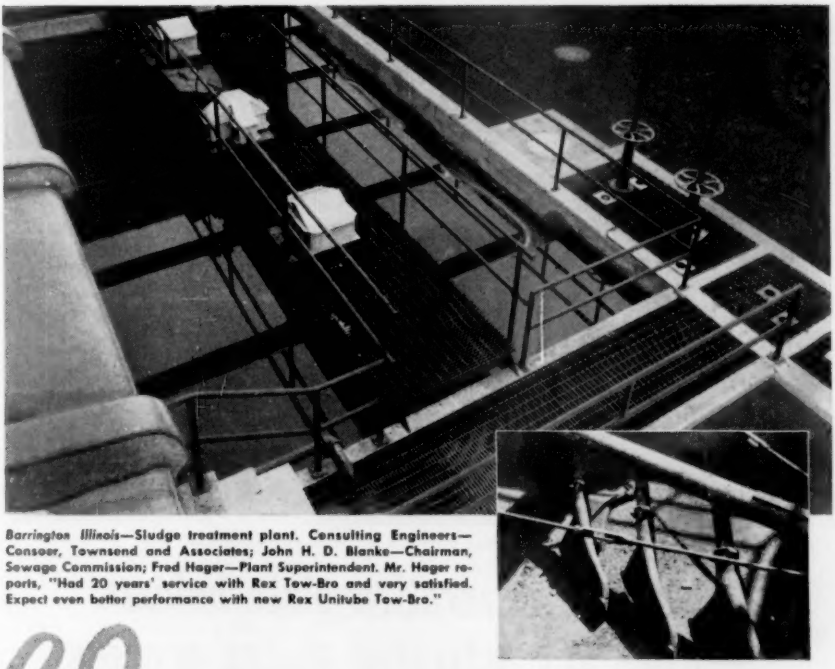

Barrington Illinois—Sludge treatment plant. Consulting Engineers—Consoer, Townsend and Associates; John H. D. Blanke—Chairman, Sewage Commission; Fred Hager—Plant Superintendent. Mr. Hager reports, "Had 20 years' service with Rex Tow-Bro and very satisfied. Expect even better performance with new Rex Unitube Tow-Bro."

20 years' steady service ...and look at its near-perfect condition!

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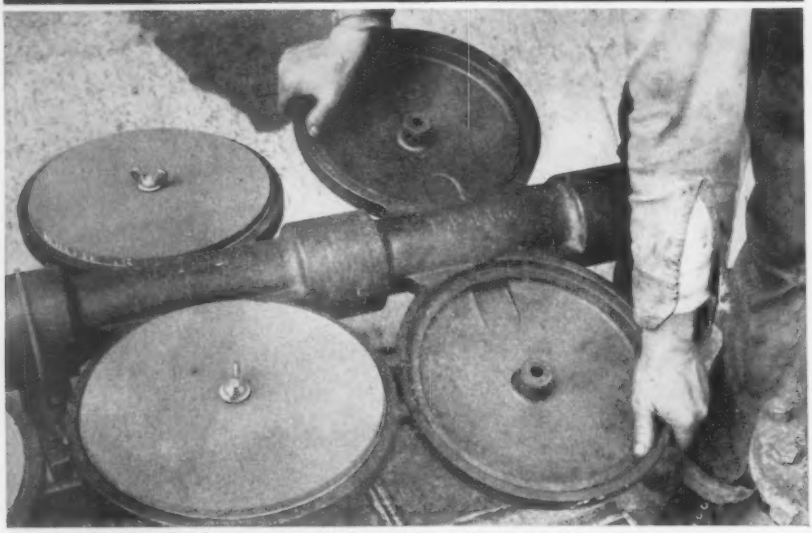

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SEWAGE AND INDUSTRIAL WASTES

Journal of the Federation of Sewage and Industrial Wastes Associations

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1956 Literature Review

A REVIEW OF THE LITERATURE OF 1956 ON SEWAGE, WASTE TREATMENT, AND WATER POLLUTION

By H. Heukelekian, *Chairman*, R. Manganelli, *Vice-Chairman*, H. Amberg, R. A. Canham, W. E. Dobbins, G. P. Edwards, M. B. Ettinger, D. G. Foulke, T. deS. Furman, I. Gellman, A. E. Griffin, H. G. Harding, R. D. Hoak, W. M. Ingram, P. W. Kabler, M. Katz, F. W. Kittrell, L. J. McCabe, P. H. McGauhey, W. A. Moore, P. K. Mueller, R. Porges, E. R. Roth, L. R. Setter, A. J. Steffen, C. M. Tarzwell, G. H. Teletzke, W. W. Towne, H. A. Trebler, E. C. Tsivoglou, and R. L. Woodward.

Committee on Research, Federation of Sewage and Industrial Wastes Associations

This first of three sections of the review deals with analytical methods and sewage. The second section, dealing with industrial wastes and radioactivity, will be published in the June, 1957 issue of This Journal. The third section, dealing with stream pollution, will be published in the July, 1957 issue of This Journal.

ANALYTICAL METHODS

Biochemical Oxygen Demand

Tidwell and Sorrels (31) in their comparison study of a 2-day versus the 5-day B.O.D. used known substrates of asparagine, glutamic acid, and glucose. These substrates were inoculated with protozoa-free sewage. They found the observed B.O.D. values versus the calculated values gave mean percentage errors of 5 to 10 per cent for the 2-day B.O.D. and 20 to 25 per cent for the 5-day B.O.D. The authors also attempted a correlation between the 2- and 5-day B.O.D. values of raw sewage, and the settleable, fixed total, and suspended solids. However, no correlation could be found between any of the various solids determinations and the B.O.D. values obtained. In approximately 50 per cent of the B.O.D. tests the 5-day value was much lower than anticipated from the 2-day value. The authors concluded that the 2-day B.O.D. value of known substrates using their sewage as inoculum was superior to the 5-day test. They also concluded that for the routine determination of B.O.D. of their particular sewage the 2-day value was more nearly correct.

Sheets and Malaney (25) studied the effects of synthetic detergents on the standard B.O.D. determination. They

found that the anionic detergents increased the apparent 5-day B.O.D. in varying degrees, while the cationic detergents had a marked inhibitory effect. The inhibitory effect of the nonionic detergents was not as great as that of the cationic detergents. This latter class in concentrations above 10 p.p.m. exhibited a marked iodine demand in the D.O. determination. The authors discussed the allowances that must be made for the effects of synthetic detergents on the B.O.D. test when studying specific sewage treatment processes.

Tidwell and Sorrels (30) made an evaluation of the relative stability test in which the various factors involved were studied. These factors included concentrations of dissolved oxygen, organic matter, bacteria, nitrates, and nitrites, and the methylene blue relative stability. A synthetic sewage of known concentration was used with a protozoa-free bacterial suspension as inoculum. An increase in the amount of organic matter or bacteria resulted in a decrease in relative stability, and as would be expected, an increase in the nitrate concentration gave an increase in the relative stability. The authors pointed out that the relative stability can be materially affected by the concentration relationship of the various entities present in a given sewage sample.

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Chemical Oxygen Demand

In many instances it is desirable to be able to estimate in a minimum amount of time the pollution load of various industrial wastes. Porges *et al.* (21) proposed a simple and rapid method for such an estimation when applied to dairy wastes. It can also be adapted to other wastes of an organic nature. The method consists primarily of diluting increments of the waste to 2.5 ml. and adding 0.0125 N dichromate in concentrated H_2SO_4. After 15 min. the mixtures are diluted and ferroin indicator is added. The appearance of a red color indicates complete reduction of the dichromate. The oxygen values are necessarily lower than C.O.D. values obtained by more drastic oxidation. In many cases the oxygen values approached the 5-day B.O.D.

Moore and Walker (17) made a comparative study of the oxidizing efficiencies of 0.025 and 0.05N $K_2Cr_2O_7$ in the C.O.D. test when the organic content was between 5 and 50 p.p.m. The authors point out that to obtain reproducible results with the 0.025 N dichromate it is necessary to observe certain precautions. These included the plugging of the condenser outlets with glass wool to prevent entrance of dust and the use of acidified distilled water for all dilution purposes. The sample size must also be selected so that not more than 50 per cent of the $K_2Cr_2O_7$ is used. When the chloride concentration is greater than 40 p.p.m. it is possible to correct for this amount only, when the silver catalyst is used. Without the catalyst the chloride correction is quantitative.

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Oxygen Demand of Effluents." *Plating*, **43**, 622 (1956).

Dissolved Oxygen

Levine *et al.* (13) developed a method for the continuous measurement of dissolved oxygen in water. This method is based on establishing a Henry's Law equilibrium between a flowing water sample and the oxygen content of a gas at constant pressure and volume. The apparatus consists of a gas analyzer, recorder, and aspirator unit together with flow and level controls, a pump, and a pressure-regulated nitrogen supply. It was found that Henry's Law was followed up to 172 per cent of saturation. The results obtained are not influenced by temperature, mineral, or organic content, aeration constant, barometric pressure, or the nitrogen content of the water.

Many colorimetric methods have been proposed in the past for the determination of dissolved oxygen. Tanaka (27) used a Mn-HCHO reagent which he reduced with powdered zinc. It is claimed that the color is stable and not influenced by nitrites, nitrates, ferrous iron, or organic matter. Oulman and Baumann (19) in their colorimetric procedure measured the iodine spectrophotometrically. They claim the following advantages for the method:

1. Standardization of solutions is eliminated.
2. Time of analysis is reduced.
3. Method is easier to use.
4. The correlation with the standard method is direct.

However, with samples containing turbidity it is necessary to compensate for the turbidity. This is done by measuring the transmission of the iodine plus the turbidity and then destroying the iodine with thiosulfate and taking a second reading of the transmission with only the turbidity present.

Davies *et al.* (6) removed interfering substances by passing the water sample through a series of ion exchange columns prior to applying the Winkler method. However, if much sulfide is present the method cannot be used.

Todt and Petsch (32) further modified their "Oxygen Plummet" in order to increase the reproducibility and eliminate the effect of the natural movement of the water on the D.O. determination. They found that electrodes of gold-amalgam with a surface area of 0.1 sq. cm. gave constant and uniform results. Details of construction of the apparatus are given in the original article. The new form of "plummet" was found to be suitable for direct measurements in waters of varying composition.

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Nitrogen Compounds

The use of ion-exchange in analytical procedures has increased greatly in the past few years. Westland and Langford (34) used such a process for concentrating the nitrate ion before applying the strychnidine colorimetric reaction. Not only was the nitrate ion concentrated, but certain interferences were removed which would have resulted in high results without ion exchange.

Kuemmel and Mellon (11) made an extensive study of *p*-phenylenediamine derivatives for the determination of nitrites. The diazonium salts of these compounds have strong absorption in the 320–400 mμ. region whereas the reagents themselves do not show marked absorption. The sensitivity of these compounds was found to compare fa-

vorably with existing methods for the determination of the nitrite ion. The molar absorbancy indices of the diazonium salts are in the 33,000 to 40,000 range. Of all the phenylenediamine derivatives studied it was found that chloro-*p*-phenylenediamine was the best.

Crowther and Large (4) made use of the blue color produced between a sodium phenoxide-sodium hypochlorite reagent and ammonia in the determination of ammonia. Beer's law is followed for amounts of ammonia up to 50 μg., but the curve is reproducible up to 150 μg. The preparation of the sodium phenoxide reagent is described in the original article.

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Sulfur Compounds

Bethke (1) determined sulfur by a wet combustion method using perchloric and nitric acids as the oxidizing agents in a special apparatus to avoid loss of SO_2. The $SO_4^=$ formed may be determined gravimetrically, but it is easier to reduce it to H_2S with a mixture of hydriodic, hypophosphorus, and hydrochloric acids. The H_2S is distilled off in a current of nitrogen and absorbed in caustic. The resulting sodium sulfide is then determined iodimetrically. The method gave recoveries of 98.7 to 101 per cent on supposedly pure sulfur compounds.

Many colorimetric methods have been proposed for the determination of inorganic sulfate. Kleeman *et al.* (10) precipitated the $SO_4^=$ with benzidine and the benzidine sulfate was recovered by means of centrifugation using glass powder as a separating aid. After removing the excess benzidine with an alcohol-ether wash the precipitate was dissolved in 1 per cent sodium borate. The liberated benzidine was then reacted with sodium 1,2-naphthoquinone-4-sulfonate. The optical density of the red color produced was measured at a wave length of 490 mμ. Beer's law is followed between sulfate concentrations of 0 to 0.50 μg. Phosphates do not interfere.

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Halogen Compounds

The determination of the fluoride ion in potable water supplies continued to draw interest during the past year. Thom and Gribkoff (28) made a statistical analysis of four different fluoride methods. These methods included the (a) Scott-Sanchis, (b) Megregian-Maier, (c) Thrun's erichrome, and (d) Rubin's methods. Three different fluoride concentrations were used, *i.e.*, 0.3, 0.8 and 1.2 mg. per liter. The results obtained indicated that Rubin's method was not suitable for routine determinations in a laboratory receiving waters from various sources. The other three methods indicated agreement within the standard deviation of the mean values obtained for each method, although the erichrome method gave consistently higher results at all fluoride concentrations considered.

Morris and Cerny (18) made use of an apparatus in the distillation of fluoride in which the air flow was precisely controlled. They were able to effectively recover known increments of fluoride even with concentrations as high as 75 mg. per liter. They pointed out that an acidity carry-over curve should be made on a particular flow-

meter to determine the optimum air flow rate.

Curry and Mellon (5) in their determination of the fluoride ion made use of a nitrogen stream in the distillation of the silicontetrafluoride. The evolved gas was trapped in a sodium borate-boric acid buffer and then hydrolyzed. The soluble silicate formed was then reacted with molybdic acid and the complex reduced to molybdenum blue. It is claimed that the method is accurate and precise in the range of 0.1 to 2.0 mg. of fluoride. The authors studied the effects of distillation time, water concentration, and 25 different ions. Beer's law was followed in this concentration range with a standard deviation of 0.024 mg.

Jones and Clark (9) in their study of the effect of aluminum on the determination of fluoride by the Megregian-Maier method made the aluminum determination more precise by acid pretreatment of the samples. By such treatment a more accurate aluminum determination could be made, thus making the fluoride results more reliable.

Lang *et al.* (12) used thorium nitrate in excess in the determination of the fluoride ion. The excess thorium was then reacted with chromeazurol-S and the resultant color measured at 595 mμ. The spectrophotometric readings were transposed to equivalent fluoride concentrations from a standard curve.

Zall *et al.* (35) were able to determine concentrations of chloride as low as 0.05 mg. per liter colorimetrically. Their method was based on the displacement of the thiocyanate ion from mercuric thiocyanate by the chloride ion. The liberated thiocyanate was then reacted with ferric iron to form the well-known colored complex.

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Organic Compounds

The increased production of organic compounds poses many new problems in stream pollution. The necessary analytical methods, however, have not kept pace with this varied production. The analytical determination of hydrocarbons (which may give rise to tastes and odors in a water supply) has been investigated by a number of workers.

Ludzack and Whitfield (15) used a continuous liquid-liquid extraction technique with air agitation for the recovery of oil from nonhomogenous samples. Infrared absorption was used in the estimation of the hydrocarbons with octodecane as a standard. Chromatographic separation on Al_2O_3 was effective for the fractionation of the mixed systems. With concentrations between 35 and 140 mg. per liter the recovery ranged from 89.5 to 99 per cent.

Wedgwood and Cooper (33) determined polynuclear hydrocarbons in industrial effluents by using a base line and measuring the peak heights, assuming that background absorption was linear over short ranges of wave lengths. They purified all solvents used and measured the peak heights at a fixed slit width in accordance with results obtained from calibration curves. Among the hydrocarbons found were pyrene, alkylpyrene, 3,4-benzopyrene, and fluoranthene. The method is claimed to be extremely sensitive for the determination of pyrene.

Sherratt (26) formulated proce-

dures for the determination of volatile oils in the range of 3 to 15 mg., 12 to 40 mg., and in excess of 40 mg. per liter. The method is particularly suited for the determination of neutral volatile oils, such as fuel oils. The author also considered the solubility of certain types of fuel oil in water. If sulfur or sulfides are present in excess of 1,000 mg. per liter interference will result.

With the increased use of synthetic detergents it has been necessary to work out more sensitive and accurate methods. Rosen *et al.* (23) by a combination of carbon adsorption and infrared spectroscopy proved that some foams encountered in water and sewage treatment plants consisted principally of surfactants of the alkyl benzenesulfonic acid type. When an additional step was added in which the surfactant was complexed with cetyl trimethyl ammonium bromide, the presence of the same class of surfactant could be demonstrated in tap water. The preliminary purification steps yielded surfactant sufficiently pure to permit the identification of its chemical class. The method is not quantitative, however.

Sallee *et al.* (24) worked out a quantitative infrared procedure for the determination of alkyl benezenesulfonates in water. The concentration range between 0.08 and 0.15 mg. per liter was studied. The procedure is quite lengthy and not suited for routine determinations since few laboratories have the necessary equipment.

Moore and Kolbeson (16) in an attempt to eliminate some of the interfering factors with the methylene blue method, used methyl green. The method is applicable to a maximum detergent concentration of 75 gamma. The reaction is carried out at a pH of 2.5 and the detergent complex extracted with benzene. At concentrations of 10 and 50 gamma the standard deviation was found to be 0.31 and 0.84, respectively. Ions such as CNS^-, NO_3^-, NO_2^-, and peptone and urine have less effect on the methyl green method than on the methylene blue method. Concentrations (in milligrams per liter) of copper (1.0), sodium borate (2,000), Cl^- (500), $PO_4^{=}$ (300) and sulfite (5.0), did not affect the method.

Thomas *et al.* (29) made use of a continuous liquid-liquid extraction technique using diethyl ether to recover volatile acids from sludge. Following extraction, excess base is added to the extract and the ether removed. The excess alkali is determined and the volatile acid content calculated from the amount of alkali used. The method will pick up some acids that are not steam distillable.

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Metallic Ions

In the differential titration of calcium and magnesium with EDTA a number of indicators have been proposed. Diehl and Ellingboe (7) used "calcein" and carried out the titration at a pH of 12. At this pH the magnesium was precipitated as the hydroxide. However, some of the calcium will also be precipitated and it is necessary to carry out the titration with vigorous stirring. Good results were obtained on various types of samples. Patton and Reeder (20) used still another indicator in their determination of calcium in the presence of magnesium, using EDTA as the titrant. This indicator produces a sharp color change from wine red to pure blue. Here also the titration was carried out at a high pH, using a monoethanolaminehydrochloric acid buffer containing complexed magnesium.

The analytical determination of the selenium ion has long been a difficult procedure. Fogg and Wilkenson (8) first separated the selenium by distillation with HBr and H_2SO_4. They found that both samples and standards must be treated exactly alike in order for the color, due to the colloidal selenium, to be reproducible. If organic material is present it is necessary to oxidize it, using H_2SO_4, HNO_3, and $HClO_4$. Cheng (3) succeeded in reacting selenium with 3,3'-diaminobenzidine. The reaction was carried out at pH 2 to 3 after which the pH was raised above 5 and the color complex extracted with toluene. EDTA may be used to complex the polyvalent metals. Strong oxidizing or reducing agents must be absent. The limit of sensitivity of the method is 50 p.p.b., using a 1-cm. cell.

Prentice and Ritchie (22) studied the effect of various inorganic ions on the determination of silica by the molybdenum-blue method. They found that $CO_3^=$, Cl^-, NO_3^-, $SO_4^=$, Al, Ca, Mg, and Mn caused no interference with the method. The presence of the dichromate ion gave high results due to an increase in color. Copper interfered and it was assumed that a compound formation resulted with the apparent ratio of copper to silica in the complex being 12:1. Both Fe^{++} and Fe^{+++} iron interfered.

Lieber (14) made a comparison of the present "standard" method for the determination of chromium with that using azide to destroy the excess permanganate. He found that with the "standard" method the developed colors should be read after a 15-min. period. It was found also that both the standards and the sample should be taken through the entire oxidation procedure. The use of azide to destroy the excess permanganate results in a much more rapid procedure.

Brako (2) determined nickel in plating baths by combining it with the purple murexide dye which forms a lemon-yellow compound. This compound is stable at a neutral or alkaline pH. The nickel was titrated with NaCN, the nickel-murexide complex not being broken up until all of the nickel ions are used to form the tetracyanide complex. At this point free murexide is liberated and the solution changed to a pinkish-purple color.

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SEWAGE

Physical and Chemical Methods

Bloodgood, Boegly and Smith (11) reported on laboratory studies of sedimentation carried out to substantiate Hazen's theory that sediment removal is dependent upon surface area and independent of depth. A model settling tank was constructed in such manner as to permit varying the length, width, and depth with a maximum possible tank size of 14 ft. by 6 ft. by 2.1 ft.

Celite was used as the sediment. The results of 35 test runs made with flows varying from 8.3 to 100 g.p.m. showed that the per cent removal obtained in a tank with baffled inlet was independent of the depth. In order to study the effect of influent turbulence the inlet baffles were then removed and a single pipe inlet was used without baffles. A series of 22 tests was made with rates of flow varying from 7 to 80 g.p.m. and inlet velocities from 1.6 to 33.9 f.p.s. The removal efficiency was found to decrease as the inlet velocity increased. Measurements were made of the removal obtained by quiescent settling in a tube and these results were compared with the results obtained with the model settling tank. By this comparison the authors computed the relative portions of the tank which were used for stilling the influent velocities and for settling. An equation which relates the length of the basin required to dissipate the inlet velocity to the product of the rate of flow and the inlet velocity is presented.

Christy (18) reviewed the fundamental concepts of sedimentation and discussed some of the practical aspects of sedimentation tank design. Of particular importance is good inlet design. The inlet of any basin should permit the energy of the incoming water to dissipate itself. Tanks that are excessively shallow at the influent end lose this damping effect. The horizontal distance comprising the inlet portion of a well designed basin should be equal to about the depth of the tank. The design features and advantages of a tank with a sloping floor are discussed. In such a tank the inlet end is deep enough to effectively dissipate the inlet velocities. The floor slopes upward toward the effluent end and the effluent is drawn off by troughs spaced uniformly across the tank for two-thirds of the length of the downstream end of the tank. Preflocculation tanks constructed integrally with primary settling tanks provide the advantages of preflocculation and at the same time facilitate good inlet design for the settling tank. Experience has demonstrated that 20 min. of flocculation of raw sewage followed by settling will reduce the suspended solids to about 45 p.p.m. regardless of the concentration in the raw sewage. Preflocculation may be accomplished by mechanical or chemical means, but the use of diffused air holds the greatest promise. Until such time as data become available, indicating the proper amount of air required, designers should provide as much flexibility in the air supply as possible. The maximum total output of 3 cu. ft. of air per lineal foot of aeration compartment is suggested.

Nicolle (63) reported on investigations on the settling of biological filter effluent at Pretoria, South Africa. He found that for humus tank detention periods of 3 hr. or less, the removal of humus was approximately 50 per cent and the suspended solids less than 20 p.p.m. He reported that there was little difference in performance between Dortmund tanks, clarifiers, and clariflocculators when operated on equal detention periods. The author reported on experiments on the chemical flocculation of biological filter effluent. He found that lime and ferrous sulfate were required in considerable quantities to achieve satisfactory results. With sufficient lime to raise the pH to 9, more than 10 grains per gallon of ferrous sulfate were required for good flocculation, but the results were little better than with 5 grains per gallon. Alum proved to be the most suitable flocculating agent; 3 grains per gallon produced good results.

Micro-straining of the humus tank effluent resulted in a suspended solids reduction of 40 to 50 per cent. It was found necessary to chlorinate the strainer at intervals of about two weeks to remove slimy growths. The microstrainer performance was not very favorable when treating effluents containing much suspended matter. In

February, 1954, five rapid sand filters were put into commission to filter the humus tank effluent in order to produce a final effluent suitable for cooling water at the municipal power station. The filtration rate used was 140 gal. per square foot per hour. Backwashing was done with final effluent; 9.5 per cent of the flow being required for this purpose. Filter runs were between 8 and 10 hr. The effluent suspended solids average 4.6 p.p.m. It was necessary to chlorinate the influent at a rate of 4.7 p.p.m. in order to keep the sand, filter walls, and pipe lines free of slimes. The author stated that the treatment of biological filter effluent by settling in humus tanks with 4 to 6 hr. detention followed by micro-straining might prove to be more economical than 2 to 3 hr. detention in the humus tanks followed by sand filtration.

Seaman (84) described the techniques employed in measuring the detention time of an industrial effluent in a settling basin using radioactive potassium[42].

Boucher (12)(13) discussed the development of the micro-strainer and its applications. The application to sewage treatment has been to reduce the suspended solids content of humus tank effluents. The humus content can be reduced from 50, 60, or even 100 p.p.m. to less than 10 p.p.m. by employing suitable fabrics.

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Biological Filtration

New Designs

Using six 3-ft. sections of 12-in. transite pipe, mounted on base plates and stacked one on top of the other, Ingram (42) constructed a filter 18 ft. deep in which the amount of sewage entering the top four sections and the amount of air entering each section could be carefully controlled. After the filter slimes had been allowed to develop, a series of six experimental runs was made, loading the filter from the top. The time of each run varied from 14 to 31 days. The hydraulic loading rates varied from 40 to 119.3 m.g.a.d. and the organic loadings varied from 2,010 lb. per acre-foot per day (1.21 lb. per cubic yard) to 4,150 lb. per acre-foot per day (2.57 lb. per cubic yard). The filter was most efficient at the maximum loading, removing 89.1 per cent of the applied load and producing an effluent containing 68 lb. of B.O.D. per million gallons (8.1 p.p.m.).

Two runs of 14 days each were made in which the sewage was applied to the top two units. The hydraulic loading was increased to 175.8 m.g.a.d. and the organic loading to 4,430 lb. per acre-foot per day (2.74 lb. per cubic yard). The resulting efficiency was 86.2 per cent. Sewage was next applied to the top three sections. The hydraulic loading was increased to 199.8 m.g.a.d. and the organic loading to 6,900 lb. per acre-foot per day (4.28 lb. per cubic yard). The resulting efficiency was 80.8 per cent.

In an effort to force a filter breakdown the hydraulic loading was changed to 119.9 m.g.a.d. with an organic loading of 13,820 lb. per acre-foot per day (8.57 lb. per cubic yard). The filter began to recover from this shock loading after the third day, and on the sixth day the efficiency was 88.1 per cent with a loading of 11,000 lb. per acre-foot (6.82 lb. per cubic yard). Microscopic examinations of filter slimes from each section were made at various loadings. Settleable solids, pH, nitrites, and nitrates were also investigated.

Using the data obtained from this study, Ingram drew comparisons between his data and the generally accepted design criteria. He found that a standard-rate filter which would achieve approximately the same removal would have to have 24 times the area and contain eight times the media volume. A high-rate filter, built to

the same standard, would have 14 times the area and contain four times the volume.

Investigations carried out in Germany and reported by Schulz (83) indicate that the tower percolating filter has a greater capacity than the normal high-rate filter. Tests were conducted with an experimental filter 1 m. in diameter, 8 m. high, and arranged in four sections. A B.O.D. reduction of 70 per cent was obtained when the filter was operated with artificial aeration at a load of 15 cu. m. of sewage per cubic meter of medium per day or 3,100 to 3,900 g. of B.O.D. per cubic meter per day. Examination revealed that reduction was carried out in the first two stages and oxidation thereafter. Experiments without artificial aeration and with loadings of 3,000 to 3,500 g. of B.O.D. per day per cubic meter resulted in a removal of 91 per cent of the B.O.D. applied. The filter effluent contained 6 p.p.m. of oxygen and 22 p.p.m. of B.O.D. per liter. Eighty-three per cent of the organic nitrogen was decomposed, and in the last stage nitrite was present.

Biological Aspects

An investigation to determine the role of insects in the process of sewage purification was conducted by Usinger and Kellen (88). Studies were carried out on two pilot-scale filters at the University of California, Richmond Engineering Field Station, and field observations were made at the small biofiltration plant at San Rafael Meadows, Calif. The two pilot-scale filters were loaded with primary settled sewage. The hydraulic loading rates varied from 0.230 to 2.760 m.g.d. per acre-foot, with the organic loading ranging from 480.5 to 5,767 lb. of B.O.D. per acre-foot per day. The filters were constructed so that a section of the filter could be removed and the zoogleal growths and insect larvae examined at three different levels. One filter, periodically dosed with DDT to prevent the establishment of psychodid larvae, was used for comparison. It was found that because the filter beds presented a narrow, restricted environment, the insect fauna was a highly specialized one and almost exclusively dipteran. Under continuous dosing, the insect larval population appeared to be at its lowest density, while the zoogleal growth reached its maximum. The amount of zoogleal slimes in the upper portions of the bed was about twice the amount in the middle of the filter and four times as dense as that occurring in the bottom of the filter.

It appears that zooglea is less efficient when it becomes too abundant. The filter with larvae maintained a constant low density of growth but was consistently more efficient in sewage treatment. Thus it is apparent that the larvae, by reducing the growth on the filter stones, stimulate the young bacteria, prevent ponding, and increase filter efficiency.

The effects of insecticide treatment on the macrofauna population, film accumulation, and efficiency of sewage percolating filters was reported by Hawkes (32). The larvae of the *Anisopus fenestrales,* one of the dominant species of macrofauna which graze on the bacterial and fungal films existing in the percolating filters, was suppressed by prolonged treatment with insecticide over a period of 15 months. It was found that while this species was almost eliminated, the number of other species of grazing fauna, especially the *Achorutes subviaticus* and *Psychoda* spp. increased so that the amount of film on the treated filter was less than on the control. The accumulation of film in both the treated filter and the control appeared to vary seasonally. The film was most abundant during the winter when the macrofauna population was smallest. The efficiency of the filters (treated and control) in removing B.O.D. also varied seasonally, with the treated filter generally more efficient.

Hawkes pointed out that while periodic application of an insecticide may restrict the grazing fauna to such an extent that ponding will result, it may be possible by a succession of applications of insecticide to change the nature of the grazing fauna to one that is more efficient in controlling film growth.

The rate at which certain bacteria and fungi oxidized organic material and the rate of increase of cell material as the result of the oxidation of a given quantity of nutrient material was reported by the Water Pollution Research Board (Great Britain) (90). Two zoogleal bacteria (Nos. 8 and 10) and four species of fungi, *Geotrichum* sp., *Sepedonium* sp., *Trichosporon cutaneum*, and *Fusarium aqueductum* were studied. The "economic coefficient" (the ratio of dry weight of growth to the corresponding weight of glucose destroyed) was obtained for each organism. It was found that the "economic coefficients" of the fungi were higher than those of the zoogleal bacteria. The rate at which glucose was destroyed was also studied. It was found that the fungus *Geotrichum* and the zoogleal bacteria were the most efficient. It was observed that in general the organisms which had a low "economic coefficient" of cell synthesis had a high rate of glucose consumption.

Detergents and Insecticides

The adequate control of sewage filter flies is often a vexing problem to sewage plant operators. Laake (46) has reported the results of tests using various concentrations of a number of insecticides. Using a solution containing 404.5 p.p.m. of an emulsifiable concentrate (10 per cent Dieldrin and 30 per cent Malathion) during the summer, it was found that 43.3 per cent of the larvae were killed. When 809 p.p.m. of Psycon was used the kill was 99.85 per cent and when the concentration was increased to 919 p.p.m. the larvae kill was complete. In the winter the insecticide was not as efficient. A concentration of 809 p.p.m. gave a 57.2-per cent kill when the air temperature was about 50° F. Another mixture (37 per cent Perthane and 18 per cent Malathion) gave a kill of 94.1 per cent when the concentration was 1,150 p.p.m., and a concentration of 1,150 p.p.m. of Malrin gave a 99.4-per cent kill. The same concentration of Malrin used in the winter gave a 63.4-per cent kill when the temperature was 50° F. and a 20.8-per cent kill at "near freezing" temperature.

It was observed that apparently worms and snails were not affected; instead their number appeared to increase after treatment with Psycon and Malrin. While Laake observed that in these tests fish life in the receiving streams was not affected, he is careful to note that the chlorinated hydrocarbons are very toxic to fish, and dilution below the hazard point should be assured before tests are made.

A comparison of the efficiency of two small-scale percolating filters, one dosed with a detergent-free synthetic sewage and the other with the same artificial sewage to which a mixture of seven proprietary synthetic detergent washing powders (equivalent to 26.5 p.p.m. of sodium dioctyl sulfosuccinate) had been added was reported by the Water Pollution Research Board (Great Britain) (90). After the filters had been allowed to mature with the artificial sewage, the detergent mixture was added to one filter influent. When first applied, little of the detergent passed through the filter. Three weeks after the first application, the amount removed had decreased to between 30 and 40 per cent; however, after 13 weeks the removal had increased to 60 to 70 per cent. A statistical analysis of the results of the B.O.D. removal indicated that there was no significant difference between the filters. A significant difference was found in the average per cent of ammonia removed and the

permanganate demand, the control filter being more efficient in both instances.

Operation and Results

An investigation to determine the efficiency of four grades of filter media was made by Hawkes and Jenkins (33). Sections of a filter bed were filled with media of four grades (Medium A, 1½-in. crushed gravel; Medium B, 2½-in. round gravel; Medium C, 1½-in. round gravel; Medium D, 1¼-in. cracked granite). Samples were taken from each of the four sections and analyzed for the 5-day, 20° C., B.O.D., 4-hr. O.A., ammonia nitrogen, nitrite and nitrate nitrogen, and suspended solids. Perforated canisters were set into each section of the filter so that the number of grazing fauna and the amount of film accumulated at various levels could be determined. It was found that on the basis of the O. A. and oxidized nitrogen, the section containing Medium D gave the best results, followed by Media A, C, and B. The average B.O.D. removal efficiency also agreed with this order; however, on occasion the order was completely changed. The amount of bacterial film at various levels of each section was determined and the abundance of three types of grazing fauna noted. It was found in all cases that the amount of film decreased as the depth increased and that the amount of film could apparently be correlated with the number of grazing fauna. While the smallest medium gave the best results, the relative increase in efficiency was not as great as might have been expected from theoretical calculations.

Fairall (26) made a statistical correlation of trickling filter loading and performance data gathered from 44 plants with single-pass filters in the upper Mississippi Valley states.

Montgomery (60) discussed the history of the development of the high-rate trickling filter and presented some interesting data on efficiency and design loading. He points out that, initially, most high-rate filters were designed to take an applied load (settled sewage basis) of 3,000 lb. per acre-foot. Experience soon indicated, however, that this loading was excessive if the plant effluent was to be discharged into a dry ditch. It is his opinion that a satisfactory effluent can be obtained when the loading ranges from 800 to 2,000 lb. of B.O.D. per acre-foot, if filters 6 to 8 ft. deep are used and adequate recirculation is provided to allow nitrification. He believes that, although the amount of B.O.D. removed will be approximately the same for filters containing the same volume of media, the deeper filters will produce a more nitrified effluent. Also presented is a loading curve showing the operating efficiency of a number of well-operated plants. It is suggested that this curve could serve as a guide for measuring the operational efficiency of high-rate filter plants. Eleven suggestions are also presented which may help in securing better operation.

An investigation to determine the degree of purification accomplished by a trickling filter at excessive loadings without recirculation and to determine the degree of purification afforded by filters in series without intermediate sedimentation was conducted by Sorrels and Zeller (85). Four primary experimental filters 4 ft. square and 6 ft. deep were dosed with settled sewage from a constant head tank. After passing through the primary filter, the sewage was applied to a corresponding secondary filter 4 ft. square and 3 ft. deep. Dosing rates were such that the organic loadings to the primary filters were 1,000, 2,000, 3,000 and 4,000 lb. of 5-day B.O.D. per acre-foot per day. The organic load applied to the secondary filters was that portion not removed, and varied widely; although it averaged 700, 1,700, 3,200, and 5,600 lb. per acre-foot per day, respectively. The hydraulic loading rates were 4.46, 8.92, 13.38, and 17.83 m.g.a.d. The experiment extended over two years to com-

pensate for seasonal variations. It was found that the pounds of B.O.D. removed per acre-foot per day by the primary filters increased from 636, at the 1,000 lb. loading, to 1,426 lb. at the 3,000 lb. loading, but dropped to 1,130 lb. at the 4,000 lb. loading. It was noted that the efficiency of the units in removing B.O.D. decreased as the loading increased. The action of the primary filter appears to be two-fold, partly flocculation of organic solids and partly biochemical oxidation, whereas the action of the secondary filter is primarily oxidation. Intermediate sedimentation does not appear to be necessary as no abnormal sludge was obtained.

Experiments to determine the oxygen requirements of percolating filters were conducted by the Water Pollution Research Board (Great Britain) (90). Using a synthetic sewage on three laboratory-scale filters, various gases were circulated through the filters by means of pumps. The gas circulated through filter No. 1 was normal air and contained about 20.6 per cent oxygen. The gas circulated through filters Nos. 2 and 3 was a mixture of nitrogen and air. The oxygen content of the air was approximately 6 per cent on filter No. 2 and 2 per cent oxygen on filter No. 3. The reduction in oxygen supplied only slightly affected the efficiency of the filters in the removal and oxidation of organic carbon. The effect on nitrification, however, was much greater. Nitrification began much earlier in filter No. 1 than in the other two, and in filter No. 3 nitrification was almost inhibited.

The sewage treatment plant at Heilbronn, Germany (69) added a two-stage facility for biological treatment, comprising trickling filters and activated sludge plant. The filters operate at a high rate for partial treatment and the effluent passes to the activated sludge tank without sedimentation. The aeration tanks operate on the principle of stage loading and step aeration.

Performance of an experimental high-rate trickling filter in Jerusalem, Israel, was analyzed statistically (73). Raw sewage with a median B.O.D. value of 950 p.p.m. was treated without operational difficulties to give effluents with a median B.O.D. value of 195 p.p.m. Average over-all plant efficiency was 79.1 per cent. This low efficiency was attributed to poor design of the secondary settling tank.

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Activated Sludge

Investigations of the mass transfer of oxygen into aeration tank liquor have been continued. Pasveer (68) concluded that with diffused air aeration absorption of oxygen at the surface of the aeration tank is of minor importance. Even in the case of low oxygenation capacities, surface aeration did not amount to more than 10 per cent. Rapid circulation of liquid in a diffused air tank decreases the rate of oxygen absorption, but this effect can be offset by distributing the air supply uniformly over the entire area of the tank bottom. Pasveer (67) believes that the purifying capacity of an activated sludge plant depends upon its capacity for adding oxygen. If the rate of oxygen addition is increased, the increased turbulence caused by the aeration reduces the size of the floc, increases its surface area,

and increases the rate of diffusion of oxygen into the sludge. The dispersed floc rapidly coagulates to its normal size as it passes from the aeration tank to the secondary settling tank. He believes that by increasing the rate of oxygen addition and the turbulence, six to eight times as much sewage can be purified per unit volume as was possible before.

Oldshue (65)(66) has studied the effect of many of the variables in the design of turbine impellers for the activated sludge process. Baffles are required to eliminate the swirling flow pattern which does not give top to bottom mixing throughout the system. Power consumption is proportional to the cube of the impeller speed, the fifth power of the diameter of the impeller, and to the specific gravity of the fluid. The dissolved oxygen level also affects the horsepower since the higher the dissolved oxygen level, the less the oxygen transferred for the same mixer horsepower and air input. The greater the liquid depth, the greater the oxygen transfer efficiency at a given horsepower and gas rate, but the smaller the actual amount of oxygen transferred per unit volume of liquid. A mixing impeller must operate within the limits of horsepower that would achieve complete circulation and suspension of solids throughout the system but would prevent an adverse effect on the settling and clarifying properties of the sludge.

Schultz and Gaden (82) have restudied the use of the sulfite oxidation method for estimating the effectiveness of aeration. They concluded that the method is adequate for comparing the performance of various types of equipment for oxygen absorption, and that it gives a relatively good picture of the behavior of a system where a highly aerobic, non-filamentous organism is propagated in a relatively simple medium.

Heukelekian and Weisberg (39) have found that the bound water content of a bulky zoogleal activated sludge is higher than that of a sludge with a low volume index, and that the bound water content can be made to vary with the settling characteristics of the sludge. The increases in sludge volume index and in bound water content, which are associated phenomena, are the result of biological processes induced by an excessive supply of available food in relation to the number of the available organisms. Neither the dissolved oxygen nor the nitrate content seem to be responsible for or are symptomatic of bulking.

The effect of various chemicals on the activated sludge process has been studied by a number of groups. Taylor, Mathews and Christenson (86) found that concentrations of nitrate nitrogen up to 4,800 mg. per liter did not inhibit sludge growth or the normal metabolic process in an experimental plant if an adequate period for acclimatization was allowed. Deterioration of the effluent did occur when the raw feed contained high concentrations of ammonia nitrogen. With sewage fed sludge, deterioration appeared at a concentration of 480 mg. per liter and a B.O.D. to nitrogen ratio of 0.2 to 1. With a synthetic sewage feed, deterioration appeared at an ammonia nitrogen concentration of 112 mg. per liter and a B.O.D. to nitrogen ratio of 3.2 to 1. McKinney, Tomlinson and Wilcox (56) observed that phenol and other related aromatic compounds are not toxic to activated sludge in concentrations up to 500 mg. per liter. Oxidation was a function of the compound and appeared to take place by beta-oxidation rather than by direct oxidation of the ring structure to cathechol. The oxidation was limited by the rate of oxygen transfer. Eckenfelder, Raymond and Lauria (24) studied the effect of various organic substances on oxygen absorption efficiency. Preliminary experiments indicated that the rate of oxygen absorption in wastes approaches that in

water during bio-oxidation, although oxygen absorption decreases with increasing sludge solids.

Papers presented at the Conference on Biological Waste Treatment (55) at Manhattan College, New York, in April, 1955 have been published in book form. About 20 papers on activated sludge are included, many of which have been published elsewhere.

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Disinfection

Heicken (34) in his work on the action of chlorine and chloramines on anthrax spores found that the amines have a stronger bactericidal action than chlorine. Experiments with other amines using monomethyldichloramine and dimethylmonochloramine showed that the introduction of the methyl group reduced both the bactericidal and sporicidal action of chloramines. A quantitative study on the reaction of chlorine was made by Friberg (29) using a radio isotope of chlorine (Cl^{36}) to show the mechanism by which chlorine kills bacteria.

Ingram (43) in dealing with the treatment of cabin cruiser wastes found that a chlorine dosage of 10 mg. per gram of body waste would give effective reduction of coliform organisms when successive charges of thoroughly ground wastes are held in contact with chlorine for a period of 30 min. Such wastes are suitable for discharge in harbor areas.

Lowe (51) found that samples of settled sewage and sewage sludge were completely sterilized by gamma irradiation from a 1.1 kilocurie source of cobalt^{60}. Dosage required for a 100 per cent kill were 5.0×10^6 rad. (radiation absorbed dose equivalent to 100 ergs per gram of material) and 2.0×10^6 rad., respectively. Except for *B. subtilis*, kills up to 90 per cent were achieved in water, sewage, and sewage sludge at dosages no larger than 7×10^4 rad.

The reduction in slime growths in chlorinated settled sewage, reported by Heukelekian and Crosby (38), revealed an incidental benefit in the disinfection of sewage. Heukelekian and Albanese (37) reported on the enumeration and survival of human tubercle bacilli and showed that chlorine residual of 1 p.p.m. after 30 min. contact time had little effect on the number of tubercle bacilli. Effective disinfection was obtained with 3 p.p.m. residual chlorine. If the contact time was increased to 1 hr., then 1 p.p.m. residual chlorine was effective.

The State of Texas, according to Herjek (36), prohibits the use of sewage for irrigation of food products even though it has been found that vegetables grown in soil irrigated with sewage were not the source of infection if the irrigation was stopped one month before harvesting and the vegetables pasteurized at 60° C. The use of treated sewage effluent is permitted for irrigation of feed and pasture crops.

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Sludge Digestion

Theory and Mechanism

In Johannesburg, South Africa, Loffell (49) used radioactive phosphorus to trace the solid phase of sludge undergoing digestion. Sludge introduced in the supernatant zone without stirring settled to the top of the lower dense sludge without penetrating it for about five days, although some diffusion of colloids into the dense sludge occurred. When the raw sludge was introduced into the digesting sludge layer it settled to the tank bottom in two days where it would be removed by any attempt to draw sludge from the unstirred tank. Stirring is recommended during the early stages of digestion.

Coackley (19) reported on the investigation of aerobic digestion of sludge. Electro-osmosis and supersonic irradiation were used to remove water. Examination of the coagulated sludge supported the protein theory of the nature of sludge. Microbiological hydrolysis proved cheaper than chemical hydrolysis, and it was concluded that aerobic digestion of sewage sludge is not economical.

In the United States, Coulter, Soneda, and Ettinger (21) successfully applied anaerobic digestion to unsettled raw sewage on a pilot-plant scale. Studies of the effects of iodine^{131} and phosphorus^{32} on sludge digestion were reported by Babbitt *et al.* (6), who found that 100 μc. of the two isotopes per liter of sludge had no effect on sludge digestion although 200 mc. of these materials reduced gas production by 10 and 17 per cent, respectively.

Gas Production

Gas production at the Little Miami sewage treatment plant in Cincinnati, Ohio, (7) amounted to 1.8 cu. ft. per day per cubic foot of digester volume. The gas yield of the primary digester amounted to 84.7 per cent of the total gas production. Vilen (89) at Kenosha, Wis., reported gas production at 8.05 cu. ft. per pound of volatile solids after allowance was made for non-gas-producing grease. The value of the gas produced amounted to $10,000 in one year. Schreiber (80) noted a gas production of 8.5 cu. ft. per capita per day in the District of Columbia sewage treatment plant. Loffell (49) found that stirring the contents of a digester increased gas production by 12 per cent. A case in which scum reduced gas production and collection until no gas was available for burning was described by Henn (35).

New Developments

Grune, Carter, and Keenan (31) studied new techniques for investigating the effects of radioactivity on the quality and quantity of sludge gas. Thermal conductivity proved difficult to use in gas analysis but gas chromatography and absorption chromatography seemed hopeful. By using a process of diffusing digester gas through the digesting sludge at Columbus, Ohio, Blodgett (10) found that the detention time in the digester could be cut in half even though the loading rate was doubled.

Additives

One report (4) described results of several months of operation of two unheated sludge digesters, one of which was treated with a digestion aid. During a five-month period 19,640 cu. ft. of sludge were withdrawn from the untreated tank, as against 7,760 cu. ft. from the treated one. Both digesters were then treated with the additive for 5½ months. The total amount of sludge withdrawn then was only 10,000 cu. ft. as compared with 65,000 cu. ft. during the same period of the previous year.

Digester Operation

The problem of scum in digesters continued to be of concern to plant operators during 1956. Crane, Fynn, and Velzy (22) reported a scum blan-

ket containing 20 to 30 per cent dry solids and measuring 15 to 20 ft. thick in an overloaded digester at Buffalo, N. Y. In "stuck" digesters receiving industrial wastes, Scherer (79) found scum 5 to 8 ft. thick, and of such consolidation that it had to be dug out by hand after the tank was emptied. Barrett (8) reported scum 9 ft. deep in a tank from which a similar amount of scum had been removed only seven months previously. Scum caused damage to pipe supports and guy wires in the digester. Gas recirculation did not prove to be the answer in this case. At Maple Cross, England, however, Finch (27) observed that gas recirculation disintegrated a 12-ft. thick scum layer containing 20.5 per cent total solids, of which 63.5 per cent was volatile matter. The suitable rate of gas recirculation was found to be 75 c.f.m. in a digester 75 ft. in diameter. Griffiths and Withnell (30) described the development of gas injection at the Maple Lodge Works in England, and its success in breaking up a scum blanket which had progressed to a thickness of 10 ft. in about three years of operation. In an open tank at Gainesville, Fla., Lohmeyer (50) found that recirculated sludge pumped in tangentially and downward at the tank wall was effective in scum control.

Alexander (1) summarized published references on chemical control by ammonium sulfate, enzymes and biocatalysts, detergents, and phosphates. He concluded that ammonium sulfate may be used successfully; that biological additives have not yielded favorable results in field tests; and that while chemicals may be found to control digester scum they must be competitive with mechanical methods if they are to be extensively adopted. Various operators (5) reported some degree of success in controlling scum by mixing, steam injection, pumping to an incinerator, and by the addition of aluminum sulfate or sodiumhexametaphosphate.

Increased rate digestion was tried in an existing plant in Bergen County, N. J. Results reported by Zablatzky, Cornish, and Adams (92) led to the conclusion that the digesters could handle at least 125 per cent of the present solids load if complete mixing were used. By mixing, a solids reduction of 60 per cent was attained, while gas production was 7.5 cu. ft. per pound of volatile matter.

Trouble from unusual constituents in sewage was reported by Robert (75). Cottonseed oil wastes with pH values varying from 1.0 to 11.0 filled the digester with excessive quantities of solids and grease. Niles (64) described troubles accompanying the practice of pumping inorganic solids to the digester whenever high sewage pumpage rates interfered with the operation of the grit removal units. Overload of the stirring mechanism caused breaks in drive gears. Unless these were repaired within 2 or 3 hr., settled solids blocked the scraper blade and the mechanism could not be started.

Digester Design

Inconsistencies in the practice of digester design were pointed out by several authors. Mau (54) noted that most regulatory agencies require per capita storage volumes of 2 to 6 cu. ft. for secondary sewage treatment plants with heated digesters; 3 cu. ft. with trickling filters; and 3.5 to 4 cu. ft. in Imhoff tanks. Thus, only 17 to 33 per cent more volume is required in an Imhoff tank, although time for digestion is 240 per cent greater (assuming 55 days at 60° F., versus 23 days at 95° F.). The shape of the digester has been given little attention except as to how it might affect supernatant quality. The result is that one-half to two-thirds of the tank is dead space, partly devoted to scum and grit. Attention is called to German designs allowing only 1 cu. ft. per capita but using a small surface area, producing about 1,600 cu. ft. of gas per square foot per day, which is more than

enough for scum control. The designs required a cone-shaped top and bottom, and a liquid depth equal to the maximum tank diameter. Design equations, costs, and other data were reported by the author.

Cerny (17) called attention to the fact that during a period when the size of other units of a treatment plant have been reduced by 50 per cent or more, requirements for digesters have been increased. This is probably because digesters have been allowed to become storage tanks for scum, silt, and dead sludge. To overcome this, a sludge thickener and an improved type of mixer are recommended. Such a procedure was cited by Eliassen and McKinney (25). At the Bowery Bay Plant, New York, N. Y., thickened sludges with 10.2 per cent solids were used to load a digester at a rate of 6.2 lb. of solids per cubic foot per month. An average detention period of 31 days gave a 61 per cent destruction of volatile matter and yielded 17.5 cu. ft. of gas per pound of volatile matter.

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Sludge Disposal and Utilization

Papers concerning three unusual topics appeared during the year. Cederquist (16) experimented with wet combustion of sewage sludge and sulfite liquor. About 40 per cent of the total organic matter was precipitated in 10 min. at 225° C., using approximately 200 l. of oxygen per kilogram of charged solids. This material was easily filtered and dewatered. Wirts (91) evaluated and recommended the disposal of digested sludge from Cleveland and surrounding communities into strip mines using force mains. Pumping stations for the system could be combined with the hydraulic transportation of coal from the mines to the cities. Pumping even 100 miles would amount to one-third of mechanical dewatering and drying costs. Bijawat *et al.* (9) chlorinated digester gas in fluidized beds of activated carbon, pumice, and cupric chloride. Almost 90 per cent theoretical yield of carbon tetrachloride was obtained.

Sludge Concentration

Concentration of combined primary and trickling filter sludges by means of a picket fence type thickener was investigated on a pilot-plant scale (14). Maximum concentration occurred at a sludge volume ratio of two days, and at minimum per cent volatile solids. An average of 8.4 per cent total solids concentration was obtained and sludge pumping was reduced about one-third over the preceding 12 months. Dust (23) reported results using a similar full-scale thickener for primary trickling filter sludge. At loading rates between 2 and 14 lb. per square foot per day, the total solids in the thickened sludge varied from 8 to 9 per cent. Whenever necessary, final effluent was returned to the thickener to maintain aerobic conditions. The strength of

the overflow amounted to less than 1 per cent of the total sewage loading.

Combined primary, trickling filter, and activated sludge was concentrated by the Laboon Process at Charlotte, N. C. (28)(71). The resulting 13 to 14 per cent sludge was digested and then dewatered on open beds. At Wilmington, Del., (74) primary sludge was elutriated to obtain increased concentration and removal of toxic compounds prior to digestion and subsequent lagooning.

Schroeder (81) reported on the basis of laboratory and pilot-plant data that centrifuging of sewage sludge resulted in the formation of three layers: 15 per cent sludge, 7 per cent sludge, and supernatant containing 9.5 per cent total solids. The final disposal of the 7 per cent sludge required chemical coagulation followed by vacuum filtration. Thus, centrifuging was considered impractical, and vacuum filters and ferrous sulfate plus lime as conditioning chemicals were chosen for the sludge dewatering process at the Niers Association.

Coackley and Jones (20) described methods and results concerning the measurement of the specific filtration resistance of sewage sludges before and after chemical conditioning. Jones (44) developed equations relating specific resistance measurements to actual vacuum and pressure filter yields. These equations were used to predict vacuum filter performance by constructing a series of graphs relating yield with (a) the initial and final moisture content, (b) drum speed, and (c) pressure over entire range of compressibility. Two experiments using full-scale rotary drum vacuum filters gave good agreement with theory.

Schepman and Cornell (78) attempted to evaluate the effect of vacuum, initial solids concentration, cycle time, and ferric chloride dosage on vacuum filter yields. Their conclusions that sewage sludges have a low compressibility, in the range of 0 to 30 in. of mercury, is contrary to any previously published results. Schepman stated (77) that vacuum filter yields, in terms of pounds of dry cake solids per square foot per hour, varied with the type of sludge as follows: 7 for primary sludges, 7 to 8 for primary digested sludges, 7 or higher for elutriated sludge but sometimes 3 and 4, 2.5 to 3.5 for all types of activated sludges.

Trubnick (87) compared standard design yields for all types of sludges before and after digestion. A sewage treatment plant designed with vacuum filters and no digestion would be more economical than one with digestion and drying beds. Health and nuisance hazards connected with the final disposal of the filter cake containing lime and ferric chloride were considered to be no greater for the fresh than for the digested sludges.

A 15 per cent saving in the cost of vacuum filtration of fresh primary sludge was realized at Minneapolis-St. Paul, Minn., (57)(58) by using Saran cloths and improving the mixing of chemicals and sludge. At Washington, D. C., (80) a reduction in drum speed and ferric chloride dosage resulted in decreasing the moisture in the cake from 72.0 to 68.6 per cent.

Lynd (52) described an asphalt-paved sludge drying bed design which permitted the use of powered loading equipment. Accumulation of sludge through sedimentation in raw sewage lagoons was not a significant factor according to a detailed survey by Hopkins and Veel (40).

Sludge Utilization

The utilization of sludge as fertilizer and soil conditioner continued to receive attention. The U. S. Dept. of Agriculture published a bulletin (3) which thoroughly reviews present knowledge and practice. In addition, studies were conducted using 18 different sludges including digested primary, digested primary-activated, fresh activated, Imhoff tank and tannery waste sludges. The complete analyses of

these materials included trace elements and nitrification characteristics. The concentrations of copper, zinc, manganese, and boron were higher than their concentrations in soil. The nitrogen-phosphorus ratios were highest for fresh activated sludge, the comparison including other types of manure, while the potash content was relatively poor. A summary of the results was published by Anderson (2). On the basis of soil nitrification the value of fresh activated sludge was about six times greater than digested sludge.

Caster (15) reported on the economics of selling dewatered and/or dried sewage sludge for 25 plants in the U. S. Leaver (47) discussed a similar topic in more detail for the Pacific Northwest. There, liquid digested sludge disposal to a single contractor has been the most remunerative. Oceanside, Calif., (76) and Wadenna, Minn., (48) reported the use of liquid digested sludge as soil conditioner and fertilizer.

Interest in the Vitamin B_{12} content of sewage sludge was evidenced by several papers. Kibi (45) analyzed dried activated sludge and found the following in gamma per gram of sample: 9.9 thiamine, 5.8 riboflavin, 1.2 pyridoxin, 32.4 niacin, 6.6 pantothenic acid, 0.7 biotin, 640 inositol, and 4.6 Vitamin B_{12}. Rabek *et al.* (70) isolated several new Vitamin B_{12} factors. Neujahr (62) did considerable work on studying relative changes in Vitamin B_{12} factors during aerobic and anaerobic fermentation. The transformations observed were explained on the basis of different species of microorganisms at work during successive stages. Vitamin B_{12} was determined in fresh primary, digested primary, digested primary-activated, fresh activated, fresh trickling filter, digested primary-trickling filter, and digested primary sludge from food wastes. Digested primary-activated sludge was found to have the highest solids content (25 mg. per kilogram), while trickling filter humus had the lowest (3 mg. per kilogram). This three-year study led to the conclusions that the Vitamin B_{12} content was governed by (a) the quality of the raw sewage and (b) the type of treatment process.

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Detergents

House and Fries (41) employed an alkyl benzene sulfonate tagged with radioactive sulfur^{35} to trace the passage of this detergent through sewage treatment processes.

From results of a plant-scale test, the authors concluded that activated sludge destroyed 80 to 90 per cent of the sulfonated detergent used, with formation of an inorganic sulfate. In laboratory studies, the oxidation of the detergent was related to the dissolved oxygen content of the mixed liquor. Sulfonate removal by activated sludge varied from 2 to 30 per cent at low aeration rates and from 30 to 90 per cent at high aeration rates.

Manganelli (53) conducted a series of laboratory experiments to determine the effects of anionic Nacconol, cationic Ceepryn and nonionic Tween 80 on activated sludge. Negatively charged Nacconol produced an adverse

effect on sewage oxidation at acid pH values; whereas cationic Ceepryn exhibited increased suppression as the pH values became more alkaline. Tween 80 was oxidized over a range of pH values. In general, endogenous respiration of the activated sludge organisms was affected to a lesser degree than the oxidative mechanisms. The effect of these ionic detergents on the oxidation of sewage by activated sludge decreased with an increase in mixed liquor solids concentration. Detergents interfere with the adsorption of colloidal food material by activated sludge organisms. The adverse action of ionic synthetic detergents involves the degradative or energy-releasing reactions and mechanisms.

Raybould and Thompson (72) carried out a large-scale investigation of the investigation of the effect of Tide and Santomerse on purification of sewage by trickling filters and by a Haworth-type activated sludge plant. The authors concluded that these sulfonated detergents should not cause undue trouble in treatment plants using trickling filters or Haworth-type activated sludge units, provided the plants are in good condition and have sufficient capacity. An adverse effect on purification took place in overloaded sewage works. Some detergent was always found in the effluent. This indicated to the investigators that, at best, the detergents are slowly decomposed biologically.

Munroe *et al.* (61) adapted methods to determine the frothing tendency of sewage at different stages of treatment. It was found that the frothing tendency of sewage increased from raw sewage to the final effluent. Anionic detergents increased the froth production of the various sewage fractions. Determination of the active anionic concentration in sewage could not be definitely correlated with the frothing tendency.

An excellent report (59) concerning the effects of detergents on sewage treatment, streams and water purification was compiled by the Ministry of Housing and Local Government of Great Britain. The report evaluates the problems caused by detergents in terms of (a) effects at the place of use, (b) effects at the sewage treatment plant, (c) effects on the receiving streams, (d) effects on the water supplies, and (e) implications of these effects.

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Sewage Works

TUBERCULOSIS TRANSMISSION BY WASTE WATERS —A REVIEW

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Editor's Note—This review is based on a study of the literature from the sanitary engineering viewpoint, as well as the medical viewpoint by the Chief of the Bureau of Tuberculosis, California State Department of Health.

Questions regarding the possibility of the transmission of tuberculosis by sewage have frequently been asked in connection with the disposal of waste waters from hospitals, tuberculosis sanatoria, dairies, and slaughter houses, and even with domestic sewage in general. Concern has been expressed about the danger of human and animal infection, particularly where these waters are re-used. The object of this paper is to provide a critical review of the literature in order to evaluate these dangers and elucidate answers to the questions which may be formulated as follows:

1. Does the sewage from institutions housing tuberculosis patients contain living tubercle bacilli?
2. Do wastes from industries which may handle tuberculous material contain living tubercle bacilli?
3. What is the effect of sewage treatment on tubercle bacilli? And the corollary question, what treatment is necessary for their destruction?
4. Is the danger from contact with infected sewage a real one from the point of view of human or animal disease?

Tubercle Bacilli in Sewage

The recovery of tubercle bacilli, the organisms which cause tuberculosis, is difficult even when favorable sources, such as sputum, are used. Their recovery from sewage is more difficult and is complicated by the presence of other bacteria which have many properties in common with the tubercle bacilli except that they are not disease producers. Some of these difficulties have been discussed by Heukelekian and Albanese (1). Despite these technical problems, a great deal of information about tubercle bacilli in sewage has been collected.

In 1882, Robert Koch, in his classic work on the etiology of tuberculosis (2), pointed out the danger of disease transmission by means of the sputum of tuberculosis patients. It was soon recognized that since sputum may find its way into the sewage of a sanatorium, sewage itself may transmit the disease.

This observation was first made by Musehold (3), who showed that sewage from a tuberculosis sanatorium contained organisms capable of producing the disease in guinea pigs. Musehold attributed the presence of living tubercle bacilli in the sewage

solely to the failure to disinfect the sputum within the institution.

Jessen and Rabinowitsch (4) also found that sewage from a sanatorium in which sputum was not disinfected contained virulent tubercle bacilli. They were able to recover the bacteria up to 100 m. (meters) downstream from the point of discharge. They attributed the disappearance of the bacilli to oxidation in the violently agitated stream and to the effect of sunlight. Like Musehold, however, they advocated that sputum be disinfected.

Numerous early 20th century investigators studied the relationship between tubercle bacilli and feces. A comprehensive literature review and report of original work was made by Laird, Kite, and Stewart (5), who concluded that "nearly all patients with tubercle bacilli in their sputum also have virulent tubercle bacilli in their feces." This observation implies that regardless of the treatment given to sputum, the sewage from institutions would be contaminated.

Working at the Trudeau Sanatorium in New York, Brown, Petroff, and Heise (6) showed again that the feces of patients with active tuberculosis almost always contained living tubercle bacilli. In continuing their study, they collected samples from the Saranac River into which the sanatorium discharged its wastes. Although tubercle bacilli were never recovered above the outfall, they were found up to 3.5 miles downstream from it.

Conroy, Conroy, and Laird (7) also studied the sewage discharged from sanatoria. Their conclusions may be summarized by the statement that "sewage from a tuberculosis sanitorium nearly always contains living tubercle bacilli."

In England, Cumins, Davies, and Acland (8) found live tubercle bacilli in the effluent of a septic tank at a sanatorium. This observation led them to recommend against the use of septic tank sludge as a fertilizer for gardens or grazing areas. The dilution of the effluent in a large stream was considered by them to be sufficient to remove hazards from that source.

More recently, Abshagen and Schinzel (9) reported recovering living tubercle bacilli from the sewage of tuberculosis hospitals even where the collected sputum was sterilized by steam and the feces of patients with intestinal tuberculosis were disinfected with Lysol.

Also working in Germany, Gabe (10) found tubercle bacilli in settled sewage from a sanatorium. He was able to recover the organisms from the samples, even in dilutions of 1 to 1,000, as far as 250 m. below the outfall. Sewage sludge also contained significant numbers of bacilli.

In studying three sanatoria in Latvia, Barons (11) found virulent tubercle bacilli up to 1,500 m. from the treatment plant in one instance, and up to 2,000 m. in the other two.

Jensen and Jensen (12), in a like manner, demonstrated viable tubercle bacilli in the sewages of sanatoria and tuberculosis hospitals in Denmark. Heat sterilization of sputum reduced the number of organisms in the sewage, but was not sufficient to eliminate the tubercle bacilli.

Stenius (13) found that the sewage from a tuberculosis sanatorium, after treatment in an Imhoff tank and passage through an outfall line 1,250 m. long, still contained tubercle bacilli.

At another German sanatorium, Kraus (14) recovered the organisms from sewage as well as from a field which had been irrigated with sewage. However, he was unable to recover the bacilli from the brook into which the sewage was finally discharged.

Larmola (15), in Finland, found virulent bacilli in the sewage of an institution housing about 300 tuberculosis patients. The organisms were recovered up to 1,000 m. below the plant.

Rimpau and Strell (16), who were concerned with the problem of tuber-

culosis in cattle, found tubercle bacilli in sewages of the sanatoria which they investigated.

From the sewage of other sanatoria in Scandinavia, Bergsman and Vahlne (17) regularly recovered tubercle bacilli. The organisms were still recoverable as far as 2,000 m. downstream from the point of sewage discharge.

Monaci (18) found similar results in Italy, as did Mom (19) in Holland. Mom reported finding organisms indistinguishable from tubercle bacilli in ditches through which raw sanatorium sewage flowed. Six months after the close of the sanatorium, tubercle bacilli were no longer found. In several other sanatoria which were studied, tubercle bacilli were recovered from the effluents of septic tanks and from ditches to which the treated sewages were discharged.

Again in Germany, Kröger and Trettin (20) studied the wastes discharged from three sanatoria and an infectious disease clinic. They found tubercle bacilli in these wastes which were capable of producing a generalized tuberculosis in guinea pigs.

In this country, Pramer, Heukelekian, and Ragotzkie (21), after developing a method for the quantitative recovery of tubercle bacilli from sewage, applied it to the study of a single sanatorium. They reported that the raw sewage contained 1,500 organisms per milliliter which were typical of those causing tuberculosis, while the effluent of a biological treatment plant, the receiving stream, raw sludge, and digested sludge contained, respectively, 10, $\pm$ 10, 100,000, and 10,000 organisms per milliliter.

Wagener, Mitscherlich, and Reuss (22), in another quantitative study at a tuberculosis hospital, found from 10,000 to 100,000 tubercle bacilli per liter of raw sewage, from 100 to 10,000 per liter in septic tank effluent, 1,000 per liter at the outfall, and occasionally they recovered a few organisms as far as 1,750 m. from the institution.

Jensen (23), who continued his earlier work on the tubercle bacillus in sewage, reported finding the bacillus routinely in the wastes from sanatoria.

In a study of veterinary problems associated with land disposal of sewage, Köser (24) examined the sewages of a large and a small town and the wastes from a sanatorium and nursing home. In 51 out of 217 samples from the sanatorium and nursing home he found tubercle bacilli. From the large town, only 3.1 per cent of the samples were positive, while the small town yielded positive results on 5.6 per cent of the samples.

Making use of a new sampling procedure, Kelly, Clark, and Coleman (25) studied the effluents from several sanatoria. At the Saranac Lake sewage treatment plant, tubercle bacilli were found at the outfall and 100 ft. downstream, but not at distances of one-half and one mile downstream. The sewages from three other New York sanatoria were also shown to be contaminated.

Tubercle Bacilli in Industrial Wastes

Jensen's monumental work on the occurrence of tubercle bacilli in sewage (26), originally published in Danish, was later summarized in English (23). He mentioned several reports on the recovery of tubercle bacilli from slaughter house wastes. In two papers by Jepsen and Christiansen which he cited, significant numbers of virulent tubercle bacilli were reported found in the wastes from some slaughter houses. In four out of the seven slaughter houses studied, the bacilli were recovered. However, in none of the dairy wastes could the organisms be found. Jensen made the point that as tuberculosis in dairy and beef herds decreased, the numbers of tubercle bacilli in the wastes from plants handling them also decreased.

In a study made by Haack (27), calculations were presented to show the numbers of tubercle bacilli which might be expected in dairy wastes.

Using two basic assumptions, namely, that 0.1 per cent of the total volume of milk handled was lost as spillage and so entered the sewers before pasteurization and that a cow suffering with tuberculosis of the udders discharges about 150,000,000 tubercle bacilli per day, Haack determined that the effluent of a plant treating about 7,600 g.p.d. of milk would contain three tubercle bacilli per liter. If the plant effluent is used for spray irrigation, a loading of 30 bacilli per 2.47×10^{-4} acre per 17 days is obtained. Under steady state conditions, Haack concluded that there would be 4.5×10^{5} living, infectious tubercle bacilli per acre.

Köser (24), in the work already cited, reported finding tubercle bacilli in the wastes from two dairies only once out of 228 samples, and never from a leather factory.

It is clear from this review that virulent tubercle bacilli may be found in the wastes of any institution dealing with people or animals suffering from tuberculosis. These organisms may be found in spite of the most careful disinfection procedures which may be followed in tuberculosis sanatoria. Neither the disinfection of sputum or feces is adequate to prevent the admission of tubercle bacilli to sewage. In industry, as long as tuberculosis infected herds exist, the possibility of contaminated discharges from dairies, slaughter houses, leather factories, and animal reduction plants also exists.

Survival of Tubercle Bacilli and Sewage Disinfection

Musehold (3) investigated the survival of tubercle bacilli under various conditions. Sputum containing tubercle bacilli was added to sewage, river water, and sludge. Virulent organisms were recovered from river water after five months of storage in either the dark or in diffused daylight. In canal water exposed to the elements, including freezing, the bacilli were found up to 4½ months later. In sludge likewise exposed to extremes of temperature and light, they survived for 6½ months. By using 340 p.p.m. of available chlorine in the form of chlorinated lime and a detention period of 2 hr., Musehold was able to disinfect sewage which had been treated by chemical precipitation. Seventeen parts per million of chlorine were not sufficient for this disinfection. A less polluted effluent was disinfected by 33 and 83 p.p.m. of chlorine.

Moeller (28), in addition to finding tubercle bacilli in the settled sewage from an institution in which sputum was adequately disinfected, also recovered virulent organisms from radishes which had been irrigated with this sewage.

Conroy, Conroy, and Laird (7) attempted to destroy the tubercle bacilli in the sewage of a sanatorium with chlorine. They found that when the effluent of an Imhoff tank was given an average dose of 12 p.p.m. of chlorine, or a peak flow dose of 6 p.p.m., it was rendered noninfective to guinea pigs.

Although concerned with avian tuberculosis in chickens and pigs, Schalk (29) made some interesting studies on the survival of the organism under natural conditions. He found that the bacilli could survive in contaminated barnyards through a rigorous winter in North Dakota. He also showed that contaminated soil could remain infective to chickens for as long as 12 months.

The effect of chlorine on tubercle bacilli suspended in tap water was studied by Kopeloff and Davidoff (30). They concluded that "the most practical disinfectant in low concentrations appears to be chlorine gas in water in a concentration of 30 to 50 parts per million when applied for five minutes."

The survival of the tubercle bacilli during storage in various media was studied by Williams and Hoy (31). Under ordinary weather conditions which exist in the south of England, the organisms remained virulent in

cows' feces exposed on pasture land for at least five months in winter, four months in autumn, but only two months in summer. When the feces were protected from sunlight, the summer survival time was doubled. With protection against earthworms, the survival in autumn was six months. In feces which were stored under laboratory conditions, the survival of tubercle bacilli varied from 12 to 24 months, depending on the source of organisms. On the other hand, in stored liquid manure, the bacteria survived for a minimum of four months.

Other studies made in the south of England by Maddock (32) (33), although plagued by technical difficulties, led to the conclusion that the tubercle bacillus can survive, during a dry summer, for 152 days in soil, in soil and dung mixtures, and in dung. Virulent bacilli were recoverable from growing grass for at least 49 days. An attempt to disinfect milk deposits and average soil with a solution of sodium hypochlorite and sodium hydroxide failed even with a final concentration of 327 p.p.m. of available chlorine and a detention period of 3 hr.

The sewage from a tuberculosis hospital, after passage through a septic tank, was chlorinated by Sollazzo (34). In preliminary laboratory studies he found that a dosage of 20 p.p.m. of chlorine for 2 hr., or 33.6 p.p.m. for 25 min., was adequate to kill the tubercle bacilli. Field studies at the same installation, using a 2-hr. contact time in all instances, showed that killing was obtained with an average chlorine concentration of 13 p.p.m. To provide a sufficient safety factor, Sollazzo suggested that a minimum of 20 p.p.m. chlorine be used for disinfection of a well-treated effluent and 40 p.p.m. for an inadequately purified sewage.

Laboratory studies by Rhines (35) on the survival of an avian strain of tubercle bacilli suspended in sewage and stream water showed that the death rate of the organisms was slow. After 93 days a significant number of bacilli remained alive. Chlorination with 91 p.p.m. of available chlorine reduced the count from 47,000 per milliliter to 20 per milliliter. Although Rhines used the organisms causing bird rather than mammalian tuberculosis, he made some general comments on tuberculosis transmission. He wrote: "The length of time that tubercle bacilli are able to survive in sewage and streams can thus be a factor in the spread of the disease. The slow development of the disease and its characteristic tendency to form latent lesions in victims are reasons that it would be difficult or impossible to trace back to water supply."

The institution at which Gabe (10) conducted his studies, composted sewage sludge for a period of three years before using it as a fertilizer. After one year of composting, he could no longer recover tubercle bacilli from the originally contaminated material.

Jensen and Jensen (12) referred to the work of Barons on sewage chlorination in which it was found that the effluent from an Imhoff tank, when dosed with 18 p.p.m. of chlorine, was made free of tubercle bacilli. After a 2-hr. contact time, a residual of 0.5 p.p.m. chlorine remained. Later, Barons (11) determined that this same dosage with a contact time of 55 min. did not provide adequate disinfection.

Jusatz (36) also investigated the disinfection of sewage from tuberculosis hospitals. He found that treatment by a trickling filter plant had no "inhibiting influence on the existence and the virulence of the tubercle bacilli in sewage." Disinfection could be accomplished with chlorine. The chlorine dose had to be adjusted to provide an excess of free chlorine. The destruction of 98 to 99 per cent of the total bacteria could be used as a guide to the destruction of the tubercle bacilli.

A series of experiments on the survival of tubercle bacilli in sewage was

made by Mannsfeld (37). She reported that sewage from Riga, Latvia, when contaminated with laboratory cultures of the bacilli, still contained organisms infective to guinea pigs after 2½ to 4 months, depending on the storage temperature. When naturally contaminated sputum was used as a contaminant in place of laboratory cultures, the survival time was increased by as much as 2½ months. The wastes from a sanatorium were likewise studied and Mannsfeld concluded "that Emscher tank and biological filter do not possess the ability to destroy the infectivity of sewage."

Jensen and Jensen (12), in studying the sewages from a number of sanatoria in Denmark, stated "it is plainly evident that the presence of living, virulent tubercle bacilli in a not inconsiderable number is a constant finding in the purified sewage from the tuberculosis hospitals and sanatoria. Even such a well-constructed purification plant as that of a sanatorium in Zealand . . . , where the aerobic bacteria content of the sewage has been reduced to about 0.2% of the original content, is apparently quite ineffective against the tubercle bacilli." The organisms were also recovered in sludge. These authors investigated the effect of chlorine on sewage disinfection. In laboratory experiments with sewage having a B.O.D. equivalent to that of a secondary effluent they found that a chlorine dose as low as 20 p.p.m. and a contact time of 40 min. disinfected sewage containing 10,000 tubercle bacilli per milliliter. In other experiments in which sputum containing the bacilli was added to sewage, 9 p.p.m. of chlorine, either as a hypochlorite or as gaseous chlorine, was able to kill 100,000 bacilli per milliliter in one hour. Field-scale studies at an activated sludge plant which produced an effluent with a B.O.D. ranging from 11 to 63 p.p.m. showed that, as a rule, a dosage of 10 p.p.m. of chlorine with a 2- to 3-hr. detention period was able to free the effluent from tubercle bacilli.

Although he did not conduct specific experiments on sewage chlorination, Kraus (14) believed that chlorination would provide the best solution to the problem of the spread of tuberculosis by sewage.

At the institution investigated by Larmola (15), complete treatment including a trickling filter was not sufficient to remove infective tubercle bacilli from the sewage. Larmola felt, moreover, that the virulence of the sewage to guinea pigs decreased with an increase in the distance the sewage was from the plant.

Sewage from sanatoria, after treatment by contact beds or after primary treatment alone, still contained virulent tubercle bacilli, according to Bergsman and Vahlne (17).

Jensen (23) (26), in expanding his earlier work with K. A. Jensen (12), studied the sewage of five towns, two of which had trickling filter plants and one provided activated sludge treatment. He introduced an interesting concept in this study of domestic sewage, namely, that of the infective ratio (f), which is the ratio of infective patients to total population served by the system. The f ratio in these instances ranged between 1:3.6 and 1:2,000. Tubercle bacilli were found in the raw sewage of all plants and in the effluents of four of them. The bacilli also were found in digested sludge in plants with ratios up to 1:600. Digested sludge which had been dried for five weeks also contained the organisms.

Laboratory studies on sewage chlorination confirmed the results reported earlier (12). Further work at two tuberculosis hospitals which provided secondary treatment showed that a chlorine residual of between 0.4 and 0.95 p.p.m., after a 1-hr. detention, was adequate for disinfection. In the one field trial described, this was equivalent to a dosage of 10 p.p.m. of chlorine. The effluent from an Imhoff tank which received similar chlorine dosages was not free of tubercle bacilli. A dosage of 25 p.p.m., which gave a re-

sidual of 3.5 p.p.m. in the contact tank effluent, did provide successful disinfection.

Destruction of the tubercle bacilli during drying of digested sludge proceeded slowly. From 11½ to 15 months were required before the organisms were no longer demonstrable. Sludge treatment for one week with 0.5 per cent Lysol or 0.1 to 0.2 per cent formaldehyde provided disinfection. Copper sulfate at a concentration of 3.1 per cent, however, was not effective. The sludge could also be disinfected with chlorine in 24 hr. at a dosage of 12 g. per 100 g. of sludge, dry weight.

Jensen made an interesting point relative to the disinfecting properties of chlorine, *i.e.*, coliform bacteria are more sensitive than tubercle bacteria. As a consequence, the former cannot be used as a guide to adequate disinfection in instances where tuberculosis is involved. This was later confirmed by Heicken (38).

Billib (39) observed that neither mechanical nor biological treatment affected tubercle bacilli present in sewage. He advocated chlorination and suggested that if all coliform bacteria and 98 to 99 per cent of all bacteria were removed the sewage would be freed of tubercle bacilli.

Work by Pramer, Heukelekian and Ragotzkie (21) and Pramer and Heukelekian (40) with avian tubercle bacilli led to the conclusion that "the removal of tubercle bacilli by sedimentation, chemical coagulation, and sand filtration is of the same order as the removal of the organisms normally present in sewage." The usual practice of chlorination could not yield an effluent free of tubercle bacilli. A free chlorine residual of 0.9 p.p.m. killed most, but not all, of the bacilli when their concentration was 118,000 per milliliter. To insure complete removal of tubercle bacilli, these authors recommended a combination of chemical coagulation, presumably with ferric chloride, sand filtration, and final chlorination to a free residual of 1.0 p.p.m.

Lindewirth, cited by Schmidt (41), studied the changes in virulence of tubercle bacilli exposed to sewage. Using guinea pigs, he found no decrease in disease-producing powers for 124 days. Longer storage resulted in decreased virulence until it disappeared after 203 days.

Chlorination studies by Bergsman and Vahlne (42) indicated that 15 p.p.m. of chlorine was adequate to disinfect sewage treated by sedimentation and a septic tank. In the absence of a septic tank, 20 p.p.m. was required. At this dosage no residual chlorine was detected after eight minutes.

The survival of tubercle bacilli in flowing sewage was studied by Kröger and Trettin (20). They introduced a culture of the bacilli into collodion bags which were suspended in the drainage channel of a sanatorium. The semipermeable bags permitted materials dissolved in the sewage to enter, but excluded particles. Thus, the bacteria were contained, but were simultaneously exposed to the conditions prevailing in the waste. Virulent tubercle bacilli were recovered up to 48 days after the bags were placed. It was noted, however, that there was a temporary decrease in the virulence of the organisms for guinea pigs on the 24th and 36th days.

Recently, Kelly, Clark, and Coleman (25) showed that a dosage of 10.7 p.p.m. of chlorine, when applied to the effluent of a sanatorium trickling filter plant, did not kill all the tubercle bacilli originally present. A 10-min. contact time was used. At another sanatorium there was some indication that a trickling filter removed or destroyed tubercle bacilli. This observation was questioned by the authors themselves since they were able to find the microorganisms 1,000 ft. below the outfall sewer from the plant.

In studying methods for the enumeration of tubercle bacilli in sewage, Heukelekian and Albanese (1) found that chlorination of sewage to an orthotolidine residual of 0.5 and 1.0

p.p.m killed roughly 50 per cent of the organisms in a contact time of 30 min. The initial concentration of tubercle bacilli was relatively high, *i.e.*, 0.34 to 0.65×10^6 per milliliter.

Applying the methods they had developed, Heukelekian and Albanese (43) found no tubercle bacilli in three domestic sewages, but found numbers ranging from 425 to 10,000 per milliliter in the sewages of four sanatoria. These authors studied, in the field and under artificial laboratory conditions, the effect of sewage treatment on tubercle bacilli. While sedimentation, septic tank treatment, trickling filters, activated sludge, and sludge digestion and drying significantly reduced the initial number of pathogens, none of these processes produced what they considered to be an adequately treated sewage or sludge. They concluded that "chlorination to a residual of 2 p.p.m. with a contact time of 30 min. or to a residual of 1 p.p.m. with a contact time of 1 hr. is required for effective destruction of tubercle bacilli."

An exhaustive study on sewage disinfection by Heicken (38) included data on the destruction of tubercle bacilli in sewage. He showed that disinfection by free chlorine or chloramine was a function of pH, temperature, and bacterial concentration; low pH, high temperature, and low bacterial numbers all favored bacterial destruction. Heicken estimated that tubercle bacilli are 10 times as resistant to chlorine as are the usual enteric bacteria, and therefore, coliform destruction can not be used as a guide to the killing of tubercle bacilli. Neither chloride of lime nor sodium hypochlorite proved adequate for disinfection. In conclusion, Heicken recommended a chlorine excess of 10 p.p.m. at a pH of 8 or greater and a contact time of 1 hr. for the disinfection of sewage from sanatoria.

Several other sources have supported or restated the conclusions given above. Among them are Heicken (44), Mitscherlich (45), and a German committee for the control of tuberculosis (46).

In summary it may be said that the survival of tubercle bacilli under natural conditions is good. The organisms persist in sewage or other contaminated materials for relatively long periods of time. Conventional sewage treatment, either primary or secondary, reduces the number of tubercle bacilli initially present, but does not eliminate them. In order to destroy all tuberculosis organisms in sewage, a combination of complete treatment, including biological purification, plus effluent chlorination appears to be necessary. A chlorine dosage of at least 20 p.p.m. with a contact time of 2 to 3 hr. or a chlorine residual of at least 1 p.p.m. after a 1-hr. contact time should probably be used.

Disease Transmission

From the foregoing it is clear that the organisms which cause tuberculosis in man and domestic animals are frequently present in sewage and industrial wastes. Unquestionably, from both the aesthetic and public health points of view this is an unsatisfactory condition. The prospect of drinking water contaminated with the oral or fecal discharges of tuberculosis patients, or of eating vegetables irrigated with such water, or of drinking milk from cows which have been pastured on land treated with this water is extremely unappealing and distasteful. On the other hand, will these uses lead to disease? What is the real or potential danger from tuberculosis spread in this manner?

While the theoretical possibility of contracting tuberculosis from sewage exists, until recently there has been little or no proof of this. For example, Brossman (47), without providing any data as to the danger, described the remodeling of a treatment plant at a tuberculosis hospital in order that "no tubercular bacilli might endanger anyone."

Maddock's (33) results with guinea pigs and calves first gave some measure of support to the disease transmission fears with respect to sewage irrigation. Grass, sprayed with 4×10^6 tubercle bacilli per square foot, was fed to guinea pigs with the results that no pigs were infected. However, when the grass inoculation was made heavier, 8 out of 10 pigs contracted the disease. Calves which had been fed similarly contaminated grass also succumbed. Although the conditions were not representative of sewage irrigation practice in that the number of organisms was huge, the demonstration of tuberculosis transmission in this way was significant.

Experiments of a comparable nature were made at the Animal Disease Station of the U. S. Department of Agriculture at Beltsville, Md., by Crawford and Frank (48). Here the sewage was contaminated by the wastes from experimental animals. An outbreak of tuberculosis in a herd had been reported several years earlier. This had led to the suspicion that the station sewage was involved and, therefore, suggested a detailed study of the problem.

Hogs, cows, and calves were fed raw sewage, secondary effluent, or sewage sludge for a six-month period. It was estimated that each hog received 67.5 gal. of sewage and that each adult cow received about 275 gal. of effluent. None of the animals showed any abnormality in weight gain and none became tuberculin-positive. Six months after the cessation of sewage feeding some animals were sacrificed. Post mortem examination again showed no evidence of tuberculosis. The authors concluded that the sewage at this institution did not contain sufficient numbers of tubercle bacilli to infect animals under conditions of gross exposure to the sewage. They asserted further their belief that this exposure was more severe than that which cattle feeding below a modern sewage treatment plant might receive and implied safety in such practice. Their results could be applied only to their institution since no data were provided on the presence of tubercle bacilli in the sewage.

Gabe (10) believed that the dangers to humans from sanatoria wastes were not great, although he advocated the practice of disinfecting sputum and providing good sewage treatment. Habs (49) was of the same opinion.

In discussing the danger of tuberculosis transmission by sewage, Larmola (15) stated: ". . . This fear is however mostly unfounded, considering that the tuberculosis morbidity among the staff of the sanatorium and of the population in the neighborhood does not seem to exceed the general morbidity to such an extent that the sanatorium may be held responsible for it." Under certain circumstances he recognized that special problems might exist because of the great resistance of the organisms.

The danger to man and animals was also considered slight by Rimpau and Strell (16). They argued, on an epidemiological basis, that the tuberculosis rate in areas around sanatoria in which both standing and flowing water contained tubercle bacilli would be appreciably greater than it actually is if sewage contaminated with tuberculous material was a real hazard. They felt that the dilution of the bacilli in the waste provided the greatest safety factor. Although enough organisms could be obtained, after concentration, to infect guinea pigs, that same number might not infect humans. Exposure of humans or cattle to the unconcentrated waste would be even less likely to produce disease. Interestingly enough, in spite of this general statement, Rimpau and Strell believed that sewage must be disinfected and, if discharged to an open stream, public use of the stream must be prevented.

On the other hand, Jensen and Jensen (12) did not discount so lightly the

dangers of exposure to wastes from sanatoria. They stated: "Considering these investigations in general, the question arises whether such an admixture of tubercle bacilli may represent any danger of infection to the population of the district concerned. It will hardly be possible to give any definite answer to this question, but it cannot be excluded that bathing in the vicinity of such sewerage outlets may imply a certain danger of infection through aspiration of infected water or by way of the mucous membranes of the eye and ear. Nor can it be excluded that a heavy storm, by which the water is atomized, may involve danger of inhalation infection in the district visited by the storm. It is positively objectionable to irrigate fields with sewage from sanatoria or use sludge from the sewage purification plant as fertilizer."

Stenius (13) presented evidence to show that previously tuberculin-negative cattle, watered in a brook to which was discharged the effluent of a septic tank at a sanatorium, became tuberculin-positive two months after the discharge was started.

The first clear-cut cases of human infection were reported in 1947 by Gaustad (50). Three children who had fallen into a highly contaminated river developed diagnosable pulmonary tuberculosis from four to five weeks after their immersion. Only 300 m. above the site of the accident the sewage from a sanatorium and nursing home discharged to the river. After careful medical scrutiny Gaustad eliminated other possible sources of the infection and concluded that the sewage was responsible. His demonstration was strengthened by the recovery of tubercle bacilli from the river water. In commenting further on his findings, Gaustad wrote: "Tuberculous infection in man contracted in this way must be presumed rare. Even so, it may be a question whether the sewage from our institutions for the tubercular ought not be altered such as to remove all danger of our rivers and lakes becoming contaminated with tubercle bacilli. . . ."

In 1950 Senecal (51) reported two additional cases of primary pulmonary tuberculosis in children associated with near drowning in contaminated water. He concluded that "the findings in the two cases described here agree with those described by Gaustad. Polluted water, especially that contaminated by the dairy industry and tuberculosis sanatoria, may theoretically spread tuberculosis disease in cattle or man who ingest the water; Gaustad has pointed out the danger of bathing in such polluted waters. The two cases of primary pulmonary tuberculosis described here are presented as a possible realization of this theory."

Heicken (44), in addition to referring to the three cases of Gaustad, mentioned another one which was observed by Professor Ickert in Germany.

In 1952, Schmidt (41) reviewed the subject of tuberculosis transmission by sewage. He cited the epidemiological studies of Schaeffer, Uflacker, and Schuette, each of whom concluded that the danger of transmitting tuberculosis in this manner was not great since no disproportionate amount of tuberculosis was to be found in the vicinity of sanatoria. Schmidt's own studies showed tubercle bacilli to be present in sanatoria wastes. He recommended that where discharges are exposed to the public or where the dilution factor is small the contaminated sewage, in addition to complete treatment, should be chlorinated or passed through a sand filter. Furthermore, he argued against the use of a nondisinfected sanatorium sewage for irrigation purposes. Schmidt believed that a chlorine dose of 15 to 20 p.p.m. and a contact time of about 2 hr. would be adequate for the disinfection of a biologically treated sewage. Schmidt also reported a previously unrecorded case

of tuberculosis in a child who had almost drowned in the stream receiving the discharge from a sanatorium.

Referring again to tuberculosis of cattle, Mom (19) reported results which indicated infections due to drinking of water contaminated by sanatoria wastes. His conclusion was that "sewage from sanatoria, communities, and wastes from dairies are undoubtedly sources of tuberculosis infection."

In two papers, Mitscherlich (45) (52) discussed the possibility of human and animal infection. He believed that unless improperly treated wastes were excluded from bathing or drinking waters and from use in irrigation of pasture land, tuberculosis transmission could occur. He pointed out that the spread among cattle of the human strain of tubercle bacilli is unlikely, but that back transmission to humans through milk was possible.

The use of sewage sprays for irrigation is considered to be especially dangerous. Not only may the crop be contaminated with tubercle bacilli (27), but also aerosol infection of man and animals may take place (23). Haack (27) recommended against spray irrigation with dairy wastes if tuberculosis existed in the herds.

Köser (24) presented evidence to show that out of 113 tuberculin-negative cattle pastured on sewage irrigated fields none became tuberculin-positive even after several months. He was also unable to isolate tubercle bacilli from these fields. Despite these negative findings and his belief that the survival time of the bacilli on soil was short, he advocated the following procedure for irrigation use of sewage: (a) sterilize the discharge of patients; (b) subject the sewage to mechanical, biological and chemical treatment; (c) allow an interval of at least 12 days between the cessation of irrigation and the beginning of pasturing cattle; and (d) prevent the cattle from coming into direct contact with either raw or treated sewage.

In England, as in the Scandinavian countries, primary tuberculosis resulting from sewage has been reported in humans. Miller and Anderson (53) observed two children who had almost drowned in sewage contaminated water and had subsequently developed pulmonary tuberculosis.

The 9 human cases reviewed in the literature cited were all associated with near-drowning in contaminated water and it may be said that this is an extreme contact. On the other hand, these cases represent definite disease directly traceable to water contamination. An editorial (54) in the British medical journal, *The Lancet*, declared that the risk of tuberculosis transmission by this means should not be overlooked: "The risk from hospitals in towns is probably small, since urban sewage is seldom discharged into waters to which the public has access, but many sanitoria are in the country, where it is not unusual to run effluent into streams used for bathing, fishing, and watering the cabbage patch. Those responsible for these institutions must not seek comfort in the notion that tuberculous infection by immersion is a rarity. The idea is a new one, and nobody can say how frequent this accident may be."

An interesting sidelight on this entire subject of tuberculosis transmission in water was brought up by Hellerström (55). He observed six cases of skin tuberculosis which followed after nose injuries in a swimming pool. Hellerström believed that he obtained quite conclusive evidence as to the source of the disease although he was unable to recover tubercle bacilli from the pool involved even though one employee was shown to have active pulmonary tuberculosis. Similar cases were reported by Cleveland (56) and Tolmach and Frank (57). Cleveland believed that cases of this kind were probably more frequent than reported in the literature. Also, he did not discount the possible transmission of other forms of tuberculosis

in this manner: "The possibility that visceral tuberculosis might be contracted from such a source can not be lightly dismissed."

It may be concluded that the presence of live tubercle bacilli in sewage is generally unsatisfactory and that, under certain conditions, it is a definite menace to public health. In the absence of direct body contact with contaminated sewage, as in swimming, the likelihood of infection is small.

Summary and Conclusions

From a review of the literature on sewage, tubercle bacilli, and tuberculosis as a clinical disease, it is apparent that health hazards may exist in the disposal of tuberculous material.

An attempt was made to answer several questions regarding tuberculosis and sewage. The following conclusions appear justified:

1. The wastes from institutions treating tuberculosis patients will almost always contain large numbers of tubercle bacilli. Disinfection of sputum and of other discharges from patients will reduce the numbers of tubercle bacilli found in sewage, but will not eliminate them.

2. Industries, such as dairies and slaughter houses, handling tuberculous animals, may be expected to discharge tubercle bacilli with their wastes.

3. Conventional sewage treatment is inadequate to significantly reduce the number of tubercle bacilli in the sewage. In order to provide adequate disinfection, complete treatment plus chlorination is necessary. The chlorine dose for a well-oxidized effluent should be at least 20 p.p.m. and the chlorine contact time should be at least 2 hr.

4. Contaminated sewage or water can produce typical tuberculosis in humans. The danger is most marked with swimming and near-drowning, but the danger associated with other uses should not be minimized nor neglected and, at the very least, it should be kept in mind.

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CONFERENCE OF FEDERAL SANITARY ENGINEERS

The Conference of Federal Sanitary Engineers, founded in 1955 as an association of practicing sanitary engineers in the United States Government, has elected the following officers for 1957–58:

President: Lt. Col. Alvin F. Meyer, Jr. (USAF).
Secretary-Treasurer: Harry A. Faber (USPHS).
Directors: Martin F. Kunkel (HHFA).
Joseph Flanagan (USPHS).
David A. Kendall (USN).

Mark D. Hollis (USPHS) and Lt. Col. Alvin F. Meyer, Jr. (USAF), are the retiring president and secretary-treasurer, respectively.

BIOTA ASSOCIATED WITH SEWAGE FILTRATION

By Albert E. Feldman

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Editor's Note—This paper completes the author's research originally reported in a preliminary report "Fungi From Trickling Filters." (This Journal, 27, 11, 1243; Nov., 1955.)

An investigation of the organisms living in the slime of various trickling filters was performed in the laboratory of the Lawrence Experiment Station, Lawrence, Mass. A preliminary report on six species of fungi has been published previously (1). The present paper deals with additional organisms associated with experimental trickling filters and sand beds and with the effluent from a sewage treatment plant.

TABLE I.—Trickling Filter Loading Characteristics

Characteristic	Filter			
	879	881	887	888
B.O.D. applied (p.p.m.)	320	320	513	513
B.O.D. loading (lb./acre-ft.)	890	890	790	790
Rate (m.g.a.d.)	2.0	2.0	1.1	1.1
Recirculating ratio	—*	1:1	5:1	—*
Hydraulic loading (m.g.a.d.)	2.0	4.0	6.6	1.1

* Single-pass filter, no recirculation.

The trickling filters studied were experimental ones, 6 in. in diameter and 6 ft. deep, filled with ¾-in. stone. Filters 879 and 881 received settled sewage and filters 887 and 888 received a mixture of sewage and organic waste. Data on the filter loading characteristics are given in Table I.

In addition to the experimental filters, a series of samples was taken from a sewage treatment plant in Spencer, Mass. This plant had an average flow of 0.58 m.g.d. The dosing rate of the intermittent sand filters was 50,500 g.p.a.d. The settled sewage applied to the beds had a B.O.D. of 110 p.p.m. The bed sampled had a flow rate of 0.17 m.g.a.d. and a B.O.D. loading of 157 lb. per acre per day. The effluent of another series of sand beds at the same plant also was sampled.

Experimental Methods

The various methods for mold isolation were as follows:

1. Slime was removed from the stones in the upper 3 to 4 in. of the filter with a sterile loop, mixed with 9 ml. of sterile distilled water, and shaken. A 0.1 ml. portion of the shaken mixture was added to pour plates of Czapek agar. Subcultures were transferred to Sabouraud agar which consisted of 40 g. of neopeptone, and 15 g. of bactoagar per liter of water. Finally, subcultures were transferred to stock culture medium which consisted of 10 g. of dextrose, 5 g. of phytone, and 20 g. of agar per liter of water.

2. Surface stones were removed from the filter and placed in a sterile Erlenmeyer flask. One hundred milliliters of sterile distilled water were added and the mixture was shaken thoroughly. One milliliter of the mixture was added to 9 ml. of sterile distilled water. Then, 0.1 ml. was pipetted into pour plates using Sabouraud agar. After each mold was isolated in pure

culture, it was transferred to stock culture medium.

3. Stones were collected from the upper part of the filter and placed in a flask containing 100 ml. of sterile distilled water. The mixture then was shaken on an oscillator for 75 min. One milliliter of the mixture was added to pour plates using Sabouraud agar, and pure cultures were transferred to stock culture medium.

4. Sand from Filter Bed H of the Spencer (Mass.) sewage treatment plant was collected and mixed with 100 ml. of sterile distilled water, and 1 ml. of the mixture was added to pour plates using Sabouraud agar and modified Waksman medium (2). Mold growth was spread more evenly on the Waksman medium and not as crowded as on the Sabouraud plates. Therefore, the molds were subcultured only from the Waksman medium and transferred to stock culture medium.

5. The effluent from the sand filters was collected with some of the scum from the drain pipe, which was discharging the effluent to a stream. One milliliter of the effluent was used in pour plates utilizing Waksman medium.

Results

Table II lists the various fungi isolated, together with their source and isolation method.

In addition to the fungi, other biological forms were isolated. In each of the sand filter beds of the Spencer sewage treatment plant, numerous larvae of midge flies were found. Since it was the middle of March, it is presumed that the larvae wintered over in the filters. A portion of the sand and larvae was mixed with 100 ml. of distilled water in an Erlenmeyer flask and stoppered with cotton. The flask was exposed to southeast illumination and the larvae developed into mature instars and pupated. Adult midges hatched out and were identified as *Polypedilum illinoense, Harnischia abortiva, Cricotopus trifasciatus* and *Glyptotendipes lobiferus.* All these species are midge flies belonging to the family Tendipedidae.

TABLE II.—Fungi Isolated from the Lawrence Filters and the Spencer Sewage Plant

Genus or Species*	Filter Source	Isolation Method
Mucor fragilis	879	1
Geotrichum candidum	879	1
Penicillium notatum†	879	1
Fusarium aquaeductum	879	1
Fusarium moniliforme	879	1
Fusarium solani	879	1
Fusarium oxysporum	879	1
Cladosporium cladosporioides	879	1
Geotrichum candidum	881	2
Trichoderma viride	881	2
Penicillium janthinellum	881	1
Penicillium lilicinum	881	1
Penicillium sp.	881	1
Fusarium oxysporum	881	2
Fusarium solani	881	2
Fusarium aquaeductum	881	2
Aspergillus niger	881	2
Phoma	881	1
Geotrichum candidum	887	3
Fusarium aquaeductum	887	3
Cephalosporium sp.	887	3
Trichoderma viride	887	3
Epicoccum purpurrascens†	887	3
Fusarium oxysporum	888	3
Trichoderma viride	888	3
Penicillium lilicinum	888	3
Penicillium sp.	888	3
Rhodotorula glutinus†	Bed H	4
Trichoderma viride	Bed H	4
Penicillium sp.	Bed H	4
Phoma	Bed H	4
Trichoderma viride	Sand bed effl.	5
Penicillium janthinellum	Sand bed effl.	5
Penicillium sp.	Sand bed effl.	5
Fusarium oxysporum	Sand bed effl.	5
Cladosporium cladosporioides	Sand bed effl.	5

* All the named fungi except *Mucor fragilis* belong to the *Fungi Imperfecti* group.
† Identification not positive.

Examination of the stones from the trickling filters showed the presence of mites, which was confirmed upon closer inspection under low magnification. These arachnids were present in the upper part of the filter on all the stones with slime. Undoubtedly, these mites were feeding on the organic matter. Two different genera were found. *Histiogaster,* of the family Acaridae (the "cheese mites") and *Histiosoma* of the family Anoetidae. The former genus is known to contaminate stored foods and the latter is usually found in damp places in decaying organic matter. Both genera are widely distributed (3). Agersborg and Hatfield (4) in their study of the Decatur, Ill., sewage treatment plant reported the presence of water mites, fly larvae, nematodes, and large num-

bers of rotifers on the stones near the surfaces of the trickling filters. In the present study, both larvae and adults of the fly, *Psychoda,* were common inhabitants of the filters. Living and dead nematodes, as well as embrionated nematode ova were usually in the slime. Rotifers and their ova were usually present in the slime together with various ciliates and one kind of suctorian protozoa.

Conclusions

A study was made of several experimental trickling and sand filters to ascertain the living organisms which inhabit such environments. Fourteen species of molds, including 10 genera, were isolated. Midge larvae collected from a sand filter bed were hatched and subsequently identified as four species of midge flies in the dipterous family Tendipedidae. Two genera of mites associated with food and decaying organic matter were observed on the trickling filter stones.

Psychoda, nematodes, rotifers, and ciliate protozoans were found to be common inhabitants of the filter.

Of the fungi isolated in this study, *Geotrichum candidum, Fusarium aqueductum,* and species of *Penicillium* have been reported present in sewage and polluted waters in the eastern United States (5). Additional mold genera associated with sewage treatment, based on the present study, are *Cephalosporium, Epicoccum, Cladosporium, Trichoderma, Aspergillus, Phoma,* and *Rhodotorula.*

The biota of sewage treatment includes a diversified group of plants and animals. Further work undoubtedly would yield many additional genera of organisms.

Acknowledgments

The author appreciates the assistance of Wm. Bridge Cooke, Mycologist, Robert A. Taft Sanitary Engineering Center, USPHS, Cincinnati, Ohio, for identifications of the fungi; W. W. Wirth, United States Department of Agriculture, for the midge identities; G. W. Wharton, University of Maryland, for the mite identifications; and C. W. Hesseltine, Agricultural Research Service, for the determination of *Mucor fragilis.* A. J. Murphy, Lawrence Experiment Station, prepared the media for the mold studies.

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SPRINGTIME PLANS

It is not too early to start planning to attend the 30th Annual Meeting of the Federation of Sewage and Industrial Wastes Associations at the Hotel Statler, Boston, Massachusetts.

October 7–10, 1957

Industrial Wastes Forum*

PRELIMINARY STUDIES—A FORESIGHTED APPROACH TO INDUSTRIAL WASTES PROBLEMS

By Edward F. Eldridge †

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Pollution control is more and more becoming a water resource conservation function with a considerable economic impact. This impact results not only from the loss of the water resource because of impaired water quality, but also from the high cost of waste disposal processes.

Officials in responsible charge of industrial operations, recognizing that their stockholder's dollars are to be spent on projects designed to reduce the effects of wastes on receiving waters, must make sure that this money, when spent, will accomplish the desired purpose. Too often in the past, this has not been the case. Industries, faced with the necessity of reducing their wastes, have often entered into high-cost projects without proper preparation or assurances as to the effectiveness of the processes or facilities used. The fault in most cases is that of the industry in not recognizing the responsibility for waste disposal and giving the problem the same attention given to other process changes and improvements.

It is encouraging to observe that this approach is changing. Most major industries are now employing full-time experienced personnel to study the waste disposal problem. This procedure is paying dividends.

In order to provide the time to properly investigate a waste disposal project, the initial studies should be well underway before the pressure and demand from the public regulatory agencies develop. Officials now are certainly aware that this demand will be made.

The initial studies vary with the problem. One area of study common to all new major problems is that of obtaining a background of information as to existing conditions in the receiving waters. This information should include water quality and biological environmental data which will be valuable for comparison after the waste discharge starts, and to establish the actual effects of the waste on the water. The background data may also be used to establish the degree of recovery or treatment required.

The use of pilot plants of substantial size prior to full-scale installation is imperative if the process or facility used has not been well established. It is usually hazardous to go from laboratory to full-scale facility without the interim pilot studies.

These preliminary studies require time and money. The money will be well spent. Timing, however, is even more important, since industry is often accused of using the studies to delay the correction of a pollution problem. To avoid such a situation, officials must anticipate the problems and prepare in advance of the demand. The papers presented on this forum are examples of such foresight.

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* The papers included in this section were presented during the Industrial Wastes Forum at the 29th Annual Meeting, Federation of Sewage and Industrial Wastes Assns.; Los Angeles, Calif.; Oct. 8–11, 1956.

† Leader, Industrial Wastes Forum.

THE VALUE OF A BACKGROUND STUDY

By Robert O. Sylvester

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A new era has commenced in the field of water pollution control. Investigations are beginning to be made to study the effect future pollutants will have on water resources before construction commences. Heretofore, most water pollution control work has been concerned with an assessment of the degree of existing pollution in a stream or waterway, and this has been followed by a campaign for pollution abatement. This kind of action is contrary to the principles of good engineering, economy, and planning.

There are many examples where, if the aspect of water quality effects had been seriously considered and evaluated prior to the construction of a certain project, the project design or location would have been different. A degree of foresight on the part of those planning projects involving a potential water quality problem will usually result in an eventual saving to the project in operating and capital costs. It will promote good public relations, and it will make for full usage of the receiving waters. No longer will stream conditions have to get worse before they can be improved.

Today, many governmental agencies and private industries are concerned with the effect their proposed projects may have on water quality. For example, the U. S. Fish and Wildlife Service and the Corps of Engineers are studying the effects proposed dams and the concomitant water uses therefrom will have on water quality in relation to the fishery. The petroleum, chemical, and wood pulping industries are conducting studies to determine the most suitable location for effluent discharge; to establish the quality of effluent necessary for a continued full usage of the receiving waters; and to document the environment in the proposed receiving waters. Municipalities are investigating their adjacent waterways for sewer outfall locations that will best disperse their effluent, and in addition they are studying the quality of effluent that must be achieved and maintained.

Purpose of Background Studies

A "background study" is a comprehensive study of a stream, lake, or tidal water in the area that would be influenced by a proposed structure or pollutant. This study is made prior to construction and final planning for the project. The study is made to:

1. Document the existing environment under all significant water conditions;
2. Obtain water movement, water usage, and topographic data so the project can be located in a manner least inimical to a continual full usage of the water concerned;
3. Use data collected for an evaluation of present water quality conditions as they have been influenced by past and present water uses, and to determine what water quality conditions may exist under a full development of the water resources;
4. Establish the water quality characteristics that must be maintained so the design, construction, and operation of the facility can be carried out to meet these requirements;
5. Obtain sufficient data on existing conditions so any future changes in

water quality or allegations of damaging pollution can be fully evaluated; and

6. Evaluate the relative importance of present and possible future water uses.

A background study must be conducted over a sufficient period of time to give data under all significant conditions of flow and climatological changes. It must obtain data on the entire environment to permit an intelligent appraisal of the conditions and to provide information for future use. (Occasional samples for water quality and a few water movement studies are not adequate.) A proper background study will take considerable time and money. However, the time and money spent on the study comprise only a small percentage when compared with the cost of the structures involved or the cost of belated pollution control measures and the damage caused by adverse water quality.

Information to be Obtained

Since the primary purpose of a background study is to insure a continued full use of the water concerned, information must be obtained relevant to the uses. Water uses include the fishery and the propagation of fish food, public and industrial water supply, recreation and scenic enjoyment, irrigation, power production, navigation, and, last but not least, the disposal of waste waters. The order of importance of these uses varies with the location and the viewpoints of those concerned.

Information to be obtained depends upon the location and structures involved, and it should consist of data on most of the following:

1. Dollar value of present and future water uses.
2. Suitability of the water for the present uses.
3. Water uses which would exist under a full development of the water resources.
4. Sources and characteristics of existing pollutants.
5. Characteristics of existing dams and impoundments.
6. Tolerance limits of water users to pollutants.
7. Critical time or season of the year for water quality.
8. Climatological, stream flow, and tidal data as applicable.
9. Water movement under various conditions of flow.
10. Water quality.
11. Biological flora and fauna.
12. Bottom deposits occurring in the body of water.
13. Physical characteristics of the water body.
14. Subsequent data needs.

Although the type of data required by each of the items in the preceding listing is apparent, certain items necessarily need some explanatory comments.

Where dams are involved, data should be obtained on the depth at which water is withdrawn through the turbines or gates, the area and character of the land to be inundated, depth of reservoir, extent of shallow areas, and the percentage of time during which all of the water passes through the turbines.

Data on the water movement under various stream flow conditions, seasons of the year, stages of the tide, and changes in the wind can be gathered from several sources. Much data can be obtained by a study of published tables, by suitable computations, and by the making of hydrographic surveys using current meters, drift poles, dyes, and various tracers.

The most essential values of water quality, depending on the circumstances, are those for temperature, dissolved oxygen, pH, chlorides, phosphates, alkalinity, color, turbidity, total solids, organic and suspended solids, carbon dioxide, hardness, sul-

fates, radioactivity, B.O.D., total organic nitrogen, coliform density, and hydrogen sulfide. Where a fishery is involved, additional data may be desired on toxic trace substances, such as the salts of ammonia, copper, zinc, lead, silver, and aluminum. If a particular industry is the principal source of existing pollution, then specific tests for the waste waters should be made, *i.e.*, lignins for the wood-pulping industry, and oils, phenols, and mercaptans for oil refining.

The collection of biological data may include the use of plankton tows, dredging and fish nettings. Intertidal and sub-tidal surveys should be made, and bottom and shoreline biological life studied.

Deposits from the bottom of the water body should be inspected for odor, appearance, texture, carbon content, and the presence of deposited pollutional material. Bottom samples can be secured by dredging or coring.

Data on the physical characteristics of the water body should include information on the surface area and bathymetry, obstructions to flow, percentage of shallow and deep areas, effect of surrounding land masses on wind action and solar radiation, and the areas where pollutional effects can be considered insignificant.

Finally, the information obtained should include recommendations on the type of additional or subsequent data needed and the preferred time of collection.

Examples of Background Studies

Multi-Purpose Dam Construction

Governmental agencies and private power companies have built and plan to build many dams, impounding reservoirs, and irrigation systems in the Columbia River Basin. To date, 40 major dams have been constructed and 74 more are proposed.

A dam, like the low-head McNary Dam on the Columbia River, will cost nearly $285,000,000, of which about 10 per cent is for facilities to pass migrating salmon. The U. S. Fish and Wildlife Service and the Corps of Engineers have become concerned about the effect this dam construction and resultant multi-purpose water usage has had and will have on the Columbia River water quality in relation to the fishery. These two agencies ask the question: is it possible that multi-purpose dam construction will so alter the Columbia River water quality that even though huge sums of money are spent for fish passage facilities, the salmon will not spawn, feed, or migrate because of an adverse water environment? As a result of this concern, the Fish and Wildlife Service together with the Chelan and Grant County Public Utility Districts have sponsored a three-year study by the University of Washington on the Columbia River Basin (1).

Forty-seven sampling stations were established on the Columbia River and its principal tributaries for the collection of data for the following purposes:

1. Documentation of the existing water quality.
2. Determination of how the previous natural water quality has been affected by (a) impoundments, (b) irrigation return flows, (c) sewage and industrial wastes, and (d) soil erosion; and the estimation of how the future water quality will be affected by these same factors.
3. Evaluation of the future water quality in respect to fish life.

Pulp Mill Location

Pulp mill sites are usually chosen on the basis of the availability of timber, processing water, suitable site for log storage areas, and a favorable labor market. Following the site selection, the engineer is then (or should be) confronted with the problem of trying to adapt the waste discharge for compatibility with the existing water uses.

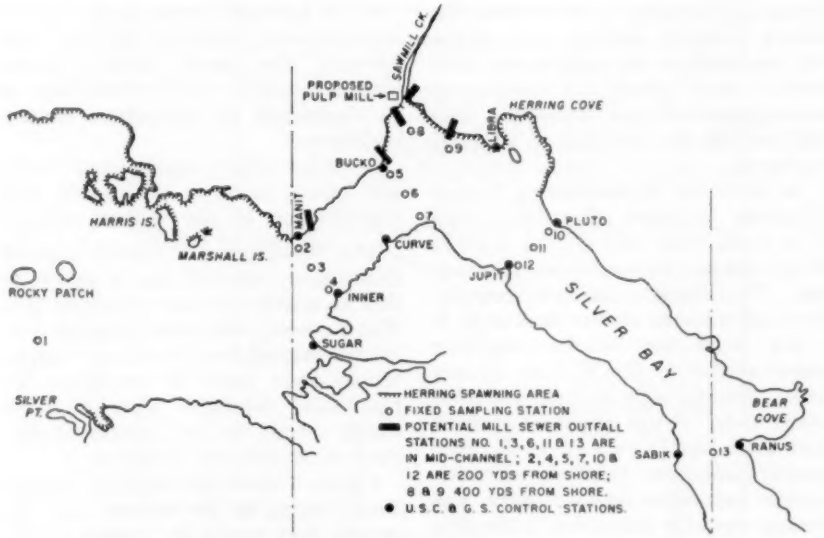

FIGURE 1.—Proposed pulp mill location on Silver Bay, Sitka, Alaska.

An example of this situation is the proposed construction of a 400-ton magnesium oxide sulfite pulp mill on Silver Bay near Sitka, Alaska (Figure 1) by the Alaska Lumber and Pulp Company. The fishery has provided the basic economy of this Alaskan area and the fishing industry has many problems of its own other than water pollution. On the other hand, Alaska has large stands of timber that should be marketed to bolster the economy of the territory. Five large pulp mills are envisaged for Alaska and the sponsors are anxious that the initial mills operate to the satisfaction of all parties concerned.

On the instance of the Alaska Water Pollution Control Board, a background study was made of the Silver Bay area (2). Oceanographical and biological data were collected by the Department of Oceanography, University of Washington, and by the Alaska Water Pollution Control Board. These data were obtained to find an answer to the following questions:

1. What are the present natural resources of Silver Bay and adjacent areas? What is their distribution and seasonal occurrence?

2. What types and quantities of waste will be discharged in the operation of the proposed mill?

3. What are the maximum concentrations of such waste under which the present resources can be maintained?

4. How much and where should this waste be discharged in order to keep the concentration from exceeding the maximum?

5. What are the mechanics of the flushing action of Silver Bay and adjacent areas?

6. What is the present areal and seasonal distribution of dissolved oxygen in Silver Bay and adjacent areas? What are the other pertinent water constituents?

The background study provided answers to these questions. Based on this study, recommendations were made for changes in the proposed mill sewer location and handling of process waters to insure viable conditions in Silver Bay for aquatic life under critical flushing conditions. If subsequent charges and counter-charges of

damaging pollution arise between the fishing industry and the pulp industry, recourse can be made to the background study where the documented oceanographical and biological data will provide the basis for an objective evaluation.

In 1950 the Weyerhaeuser Timber Company proposed the construction of a kraft pulp mill on the Willapa River estuary in southwest Washington. The company had two prospective mill sites as shown in Figure 2.

Not much was known regarding water quality of the Willapa estuary or of Willapa Bay and its extensive oyster beds. It was generally assumed that these waters were of fairly good quality since the tributary domestic sewage population was not large, and because the only industries in the area that might affect water quality were sawmills and log storage grounds. The questions which concerned the company were:

1. Can a modern 235-ton kraft pulp mill be built at either location to discharge waste waters to the estuary without seriously affecting the water quality?

2. If the mill wastes could not be discharged at either of the two sites selected, how much farther downstream would the waste waters have to be discharged for compatible estuary conditions?

3. What effect would dilute kraft mill wastes have on the growth and reproduction of the Willapa oyster?

The Washington Pollution Control Commission entered into a study to find an answer to these questions (3). Water quality data were obtained during the critical flow season and computations were made to determine the theoretical detention times a waste would remain in the estuary if discharged at different locations.

Figure 3 shows the dissolved oxygen then existing in the estuary and the oxygen that would be present if the waste were discharged at different locations on the estuary. The low D.O. values found were unexpected. Essentially they could be attributed only to decomposing sawdust, wood chips, and bark. It was determined that the waste water would have to be discharged seven miles down the estuary from the proposed plant sites if satis-

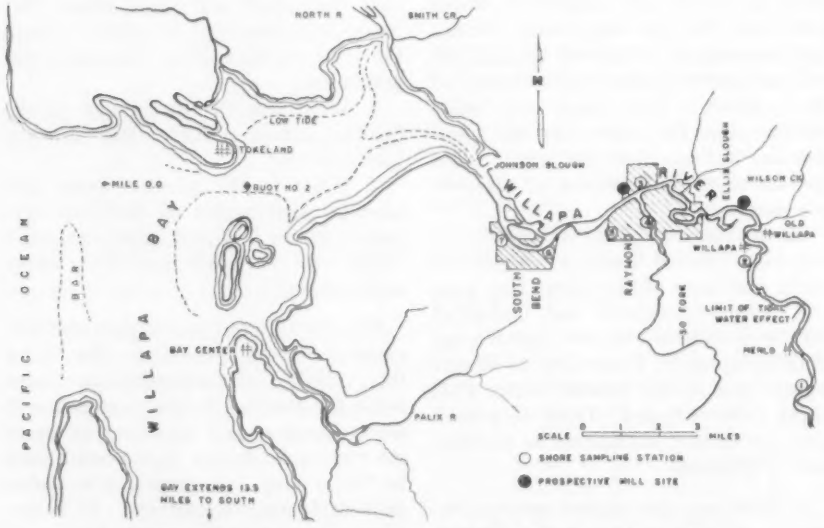

FIGURE 2.—Proposed pulp mill location, Willapa River, Wash.

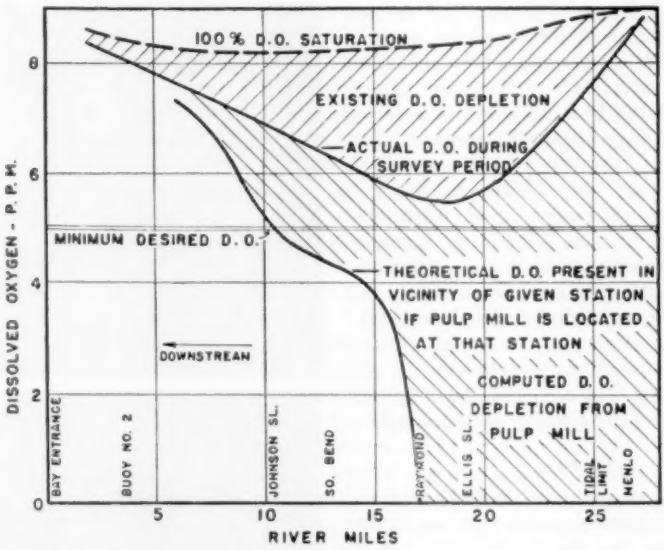

FIGURE 3.—Existing and theoretical D.O. values, Willapa River estuary.

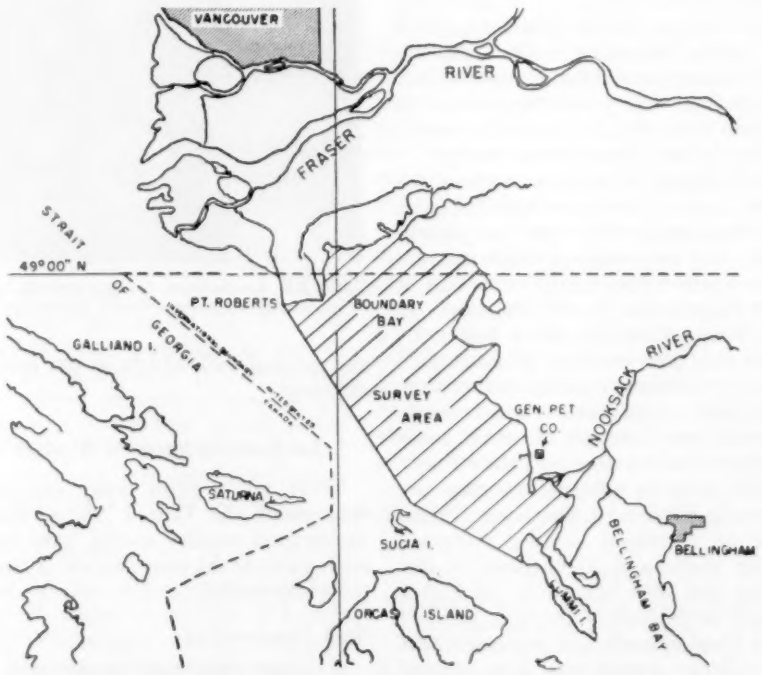

FIGURE 4.—Survey area for oil refinery background study.

factory D.O. conditions were to be maintained at all times.

Data were not available for predicting the toxic effect of these dilute wastes on the Willapa oyster. Accordingly, the Weyerhaeuser Company built a biological laboratory on Willapa Bay for studying the oyster and its response to an environment of dilute kraft mill wastes. This is an example of an industry and water pollution control authority working together on a background study that probably saved not only money and perhaps the stream, but will prevent the continual harassment that attaches itself to all concerned with a badly polluted river.

Petroleum Refinery

In 1954 the General Petroleum Corporation constructed the first major oil refinery in the Pacific Northwest and spent $1,500,000 on waste water treatment facilities. In addition, this company had a background study (4) conducted on the 215 square miles of adjacent Georgia Strait (Figure 4) prior to refinery operation. The adjacent waters support a valuable crab, oyster, and bottom fishery and serve as a migration route for salmon in the multimillion dollar Fraser River fishery.

Periodically, studies are made of the water quality and shoreline conditions for comparison with the background study and to provide a check on refinery waste water treatment. This is vital information for the company. If the fishing industry has a bad year, there may arise serious allegations of refinery pollution and fish destruction.

Typical organisms and debris screened from a sample of bottom muck dredged from an area near the refinery outfall prior to refinery operation are shown in Figure 5. The muck had an odor of hydrogen sulfide, contained empty shells and worm cases, a few worms and little other life. If such a sample of the bottom had been dredged after plant operation, it is possible that the refinery would have been blamed for the hydrogen sulfide, dead clams, and general lack of life in the bottom sediment.

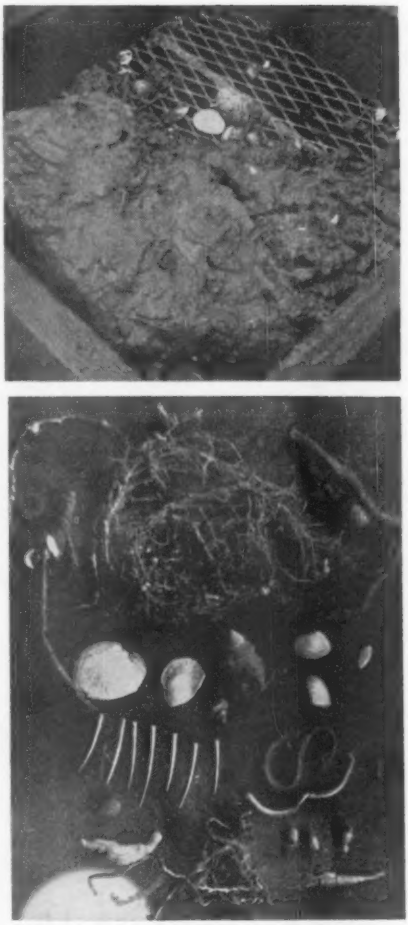

FIGURE 5.—Bottom dredge sample near proposed refinery effluent discharge.

Lack of Background Studies

There are a great many examples throughout the United States where background studies should have been made prior to the construction of water pollutant works.

Dam Construction

A large dam was constructed in southwest Washington several years

ago upstream from a salmon hatchery that used water from the stream. After construction of the dam and release of impounded waters, the fish in the hatchery died and the hatchery was closed.

Cause of the fish kill was never definitely determined (5). Several causes were given. Among them were water quality changes brought about by (a) the release of impounded waters with their decomposition products, (b) the leaching of alkali from the dam itself, (c) the leaching of toxic materials in the inundated reservoir area, or (d) a rise in water temperatures. Improper arrangements for hatchery operation were also considered as a possible cause. A background study of the stream environment prior to dam construction would have provided a basis for a sound evaluation of this problem.

Pulp Mill Location

A pulp mill was built in an oyster growing area on Puget Sound at the head of a narrow inlet which received little flushing from fresh or tidal waters. Since construction, the company has spent millions of dollars on process changes, court costs, the purchase of oyster lands, and on changing the method of waste water handling.

Today, the charges by the oyster industry that the pulp mill is destroying their product are stronger than ever. There are beliefs that the oyster mortality may be caused by (a) the method of oyster growing, (b) the siltation of the beds, or (c) by an unknown oyster parasite. Data are not available to positively prove either viewpoint. A thorough background study, even at this late date, would shed much light on this problem.

Municipal Sewage

One of the principal recreational and scenic assets in the City of Seattle is Lake Washington. As the metropolitan area has grown, more and more treated and untreated sewage has been discharged to the lake. Recent studies by the Washington Pollution Control Commission (6) and the University of Washington (7), have indicated large algal blooms in the lake. Fear that the lake would soon become eutrophic because of the addition of sewage nutrient caused a demand for removal of all sewage from the lake. Preliminary plans were quickly drawn for the removal of sewage and its discharge to the Duwamish River and Puget Sound.

These plans have now been deferred because there is insufficient background data on such factors as the suitability of the proposed points of sewage discharge, the addition of algae nutrients from sources other than domestic sewage, and the actual increase in the lake algal populations. A comprehensive engineering study is now being undertaken to provide the necessary background data.

Conclusions

Public, industrial, and recreational water supplies can be maintained in a useful state only by foresight on the part of those planning and designing structures which in some manner affect the water quality of a stream. Without a background study the use of foresight has a limited value.

Many environmental conditions, other than those imposed by man, affect the quantity, appearance, condition, and presence of aquatic life in a given area. Any evaluation of water quality, or aquatic life, should be made only after the entire environment has been carefully scrutinized over a period of time. A study of the nature outlined herein may be useful in helping to prove or disprove allegations of fanciful or real pollution damage.

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STANDARDS FOR PROTECTION AGAINST RADIATION

The U. S. Atomic Energy Commission has issued a regulation (Part 20) establishing standards for the protection of atomic energy workers and the public against radiation hazards arising from activities licensed by the Commission. The regulation was first published in July, 1955 (THIS JOURNAL, **28**, 3, 322; Mar., 1956) as a proposed rule. Since then it has had the benefit of study by many interested persons and organizations.

The regulation prescribes limits for governing the exposure of workers to external radiation, concentrations of radioactive material which may be discharged into the air and water, and disposal of radioactive wastes. Permissible limits, which except for minor changes are the same as those contained in the earlier proposed regulation, agree substantially with the current recommendations of the National Committee on Radiation Protection in NBS (National Bureau of Standards) Handbook 52, "Maximum Permissible Amounts of Radioisotopes in the Human Body and Maximum Permissible Concentrations in Air and Water" and NBS Handbook 59, "Permissible Dose from External Sources of Ionizing Radiation."

The regulation applies only to activities licensed by the Atomic Energy Commission. It does not cover radiation sources such as X-ray and radium. One of the purposes of the regulation, however, is to assure that exposures to radiation from licensed material, when added to exposures from other radiation sources, do not exceed the permissible limits.

Principal change affecting waste disposal has been to expand the waste disposal sections of the regulation to set forth minimum requirements applicable to the majority of users, particularly small users and those whose problems are least complicated. Special problems are to be directed to the Commission.

Copies of the complete regulation are available from: United States Atomic Energy Commission, Washington 25, D. C.

PILOT STUDIES TO PREDICT EFFECTS OF WASTE ON RECEIVING WATERS

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In any plans for the location of a pulp mill in the vicinity of Aberdeen, Wash., the distribution of the effluents from the mill must be given careful consideration. If the mill outfall were located on the Chehalis River itself, the possibility of effluent back-up upstream as far as Montesano is a distinct possibility. During seasons of low flow runoff, the probabilities of effluent concentrations in excess of certain maxima, damaging to fish life, in the river and its estuary, must be considered.

This report consists of (a) a volumetric study of the harbor and river, (b) a description of the construction of a dynamic model of the system, and (c) a study of the distribution of an added component throughout the system under different conditions of river flow and plant size with the mill outfall at different locations.

Grays Harbor and the Chehalis River estuary cover an area of approximately 90 square miles, of which only about 40 square miles are covered by water at mean lower low water. Large areas are exposed even at half tides.

From the mouth of the Chehalis River to the main channel, just inside the bar, there are two channels through which the exchange of water due to tidal action is carried out. The North Channel is the principal one and is maintained as the regular ship channel. The lesser, South Channel, is not improved for shipping. Most of the load of filling and emptying the upper harbor with tidal changes is carried by the North Channel.

Four river systems (Humptulips, Hoquiam, Wishkah and Chehalis), as well as several minor streams, discharge directly into the harbor. Of all these, the Chehalis is by far the most important, as it serves more than 75 per cent of the total harbor drainage area. The Chehalis has a maintained shipping channel (200 ft. wide by 26 to 28 ft. in depth) as far as Cosmopolis, and has 10 ft. of depth to Montesano. Tidal effects are felt farther upstream from Montesano.

The total discharge of the Chehalis system varies widely, seasonally, being as high as 40,000 c.f.s. or more in the winter and early spring months, and dropping to below 750 c.f.s. during the dry periods of summer and early fall.

The bay-river system might be considered as a long-stem funnel in which fresh river water is flowing continuously through the stem and salt water (in considerably greater quantities) is periodically moving in and out of the funnel end. Any third component material which is added to this system is subjected to these two primary actions. If the addition is made in the stem of the funnel, the diluting and purging action consists primarily of river flow. If the addition is made in the large section of the funnel the effect of fresh water flow is minor compared with the tremendous volume changes occurring with the periodic saline flushings. In the stem, the time required to remove a given increment of the third component depends upon how close this addition is made to the "mouth" and the magnitude of the fresh water flow through the stem.

In the bay-river system the river might be considered as the stem of the funnel and the bay the funnel itself

If the third component, such as a pulp mill effluent, were discharged at Montesano, its equilibrium concentration should closely approximate the ratio of the rates of sewer discharge to river flow. If the point of discharge were moved downstream there would be a small but definite increasing effect of the tide and one would expect the concentration to become, decreasingly, somewhat less than the ratio of these rates. However, since the tidal volume effect is relatively minor in the river, no great change would be expected as long as the discharge was in the river itself; that is, down to the general location of Aberdeen. At about this point, however, the tidal changes become highly significant and the river flows less effective; therefore, the basis for estimating the resulting concentration shifts. The only data available for making such estimates are the salinity gradients and certain averaged figures on bay volumes. The effects of such indeterminate characteristics as configuration of the bay area are almost impossible to calculate.

It was because of the difficulties of calculating the degree and extent of dilution of mill effluents that it was decided to construct a dynamic model of the bay-river system.

To facilitate the studies of the system, the bay and river were divided into nine primary areas, the divisional boundaries being more or less arbitrary. Figure 1 shows the arbitrary sections. As pointed out later, the volumes of water involved were determined for each of the nine sections. Other volumes considered were the flow of the Chehalis River (based on U. S. Geological Survey Water Supply Papers), the "tidal volume" (that is, the increase in volume from mean lower low water to mean higher high water), and the static volume (the volume of water in the system at MLLW). Mill flow volumes were based on data from the various mills of the Weyerhaeuser Timber Company.

In Figure 2 an attempt has been made to show pictorially how these various volumes compare. The areas shown are proportional to the volumes of water involved. It can be readily seen how the river itself (Sections 9, 8 and 7) is rapidly purged by high flows and why the detention times of a third component (such as a mill sewer effluent) must be short during such high flow seasons. It is, similarly, obvious why the detention times during periods of low river flow are long, and why, with a reciprocating tidal action, the difficulties of emergence from the river portion of the system

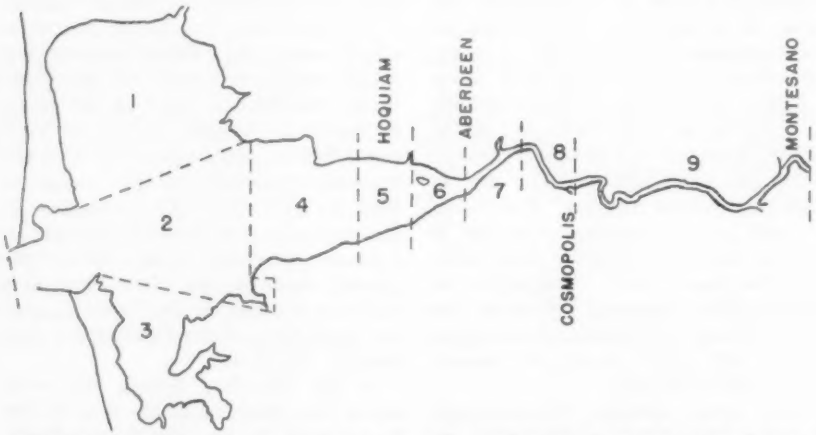

FIGURE 1.—Arbitrary sections of Grays Harbor and the Chehalis River Estuary for volume and flow calculations.

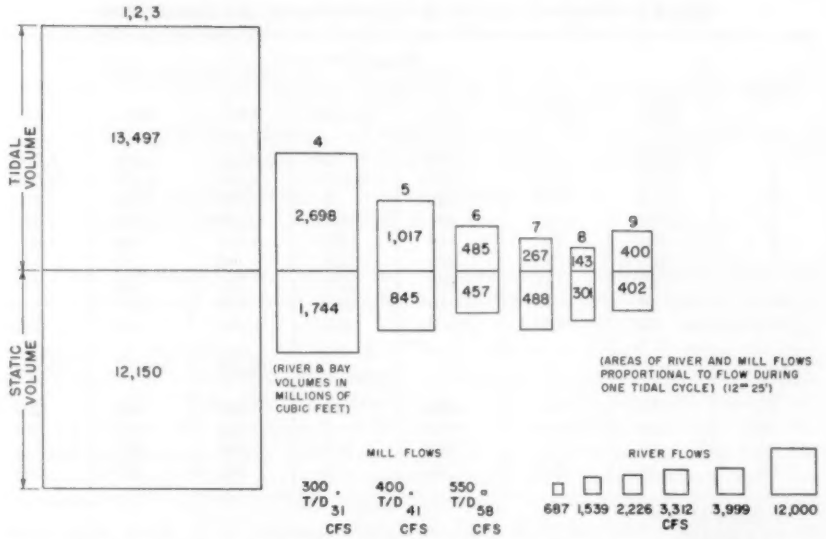

FIGURE 2.—Comparative volumes of static and tidal volumes in the estuary, mill flows, and river flows.

into the bay portion are greatly increased.

Volumetric Analysis of Harbor and River

As a preliminary to a hydrological study of the system, a volumetric breakdown of the area was made. The data for the study were obtained from U. S. Coast and Geodetic Survey Map No. 6195, a navigation chart giving area and depth details from the Grays Harbor Bar on the west to Montesano on the east. As previously mentioned, arbitrary sections were marked off on this chart. The entire area, including tidal flats, shoal areas, and deep water channels, was cut out and weighed. By cutting out and weighing carefully scaled areas of the same map sheet an area unit-weight factor was determined. In this way the area of each section was determined. Then, by further removal of the tidal flat areas, followed by weighing, the actual tidal flat areas were determined.

Similarly, the areas of the deep-water channels were calculated. Average depths were obtained by averaging the soundings indicated on the chart. These chart soundings are all at mean lower low water. The volumes of the sections from South Aberdeen to Montesano were taken from the condition charts of the Army Engineers (1943, latest available). Since the mean higher high water tide at Point Chehalis (on the west) is 9.0 ft. and at Aberdeen (on the east) is 9.9 ft., a value of 9.5 ft. was assumed for the entire area. It was further assumed that the average depth of the tidal flats would approximate a half-full tide; that is, 4.75 ft. Hence, the following was used to estimate the sectional volumes:

Volume of tidal flats	= Area of tidal flats × 4.75
Volume of channels and shoals (above MLLW)	= Area of channel and shoals × 9.5
Volume of shoals (at MLLW)	= Area of shoals × avg. of soundings
Volume of channels (at MLLW)	= Area of channels × avg. of soundings.

TABLE I.—Volumetric Analysis at Grays Harbor and the Chehalis River

Section No.	Volume (10^6 cu. ft.)						
	Tidal Flats	Channel and Shoals[1]	Shoals[2]	Channels[2]	Tidal	Static	Total
1	3,373	1,853	1,654	0	5,226	1,654	6,880
2	1,373	5,197	3,157	6,315	6,570	9,473	16,043
3	912	789	1,023	0	1,701	1,023	2,724
4	1,254	1,444	1,097	647	2,698	1,744	4,442
5	304	713	619	226	1,017	845	1,862
6	105	380	249	208	485	457	942
7	29	238	262	226	267	488	755
8	10	133	16	285	143	301	444
9	20	380	0	402	400	402	802
Total[3]	—	—	—	—	18,507	16,387	34,894
5A	63	275	255	210	338	465	803
5B	239	427	319	0	665	319	984
6A	41	179	109	217	220	325	545
6B	65	202	128	0	267	128	395

[1] Above MLLW.
[2] At MLLW.
[3] From bar to Montesano.

The sum of the volume of the tidal flats plus the volume of the channel and shoals (above MLLW) was considered to be the volume of tidal water moving in from the ocean on each rising tide, and in this report is termed the tidal volume. The sum of the volume of the shoals (at MLLW) plus the volume of the channels (at MLLW) is considered to be the volume of water remaining in the system at low tide, and is termed the static volume. The sectional breakdown of these data is given in Table I. The State of Washington reports (1) that the volume from Montesano to the bar at low tide is $16{,}453 \times 10^6$ cu. ft.; at high tide it is $34{,}399 \times 10^6$ cu. ft. The value at low tide corresponds to the authors' so-called static volume, which has been calculated to be $16{,}387 \times 10^6$ cu. ft. The difference of $17{,}946 \times 10^6$ cu. ft. between the high and low tide values reported by the State of Washington corresponds to the tidal volume of $18{,}507 \times 10^6$ cu. ft. It seems reasonable to assume that the method of calculating these volumetric data is satisfactorily accurate.

Dynamic Model of Harbor and River

Plans for the construction of a model of the system called for a series of tanks representing the volumes of the various arbitrary sections. A complete tidal cycle of 12-in. amplitude each 30 min. was decided on. This would give 24 cycles, or approximately one month of natural tides, per day. For simplication, all tides were to be identical in height and duration.

A volumetric scale of 1 to 748×10^6 was selected as a natural one. That is, for example, 100×10^6 cu. ft. was called 1 gal. of scaled model capacity. Thus, the tidal and static volumes of Table I were reduced to gallons, and thence to cubic inches. Since the tidal volume was to have the vertical dimension equal to 12 in. in all sections, the tidal area was set, and this same area was then the area of the static volume. On this basis the static depth was calculated.

As an example, the calculations for Section 7 were as follows:

Tidal volume (natural) = 267×10^6 cu. ft. (Table I)
Static volume (natural) = 488×10^6 cu. ft. (Table I)

Tidal volume (scaled) = 2.67 gal. = 617 cu. in.
617/12 = 51.4 sq. in. = tidal area (scaled)

Static volume (scaled) = 4.88 gal. = 1,127 cu. in.
1,127/51.4 = 21.93 in. = static depth (scaled)

Total depth of tank = 12 + 21.93 = 33.93 in.
Area of tank = 51.4 sq. in.

A 3-in. freeboard was added to all tanks to prevent slop-over at high tide.

Because of the large volumes involved, Sections 1, 2, and 3 were combined into one. One available large wood stave tank was partitioned off to give the proper area. The portion of the tank "outside" the partition was considered as "ocean." All other tanks were made of plexiglass. Sections 4, 5, and 6 were approximately square. Sections 7, 8, and 9 were made as narrow as possible to simulate the geometry of the "river" portion of the model. Table II gives the dimensions of the various tanks comprising the system.

In Sections 6, 7, 8, and 9 baffles were installed to increase the "effective length" of each section and so more closely simulated the configuration of the system in nature. This increased the effective number of sections to 27.

After some preliminary tests the model was further modified to more closely conform to the bay-river system. Sections 5 and 6 were divided to separate the North and South Channels. The North Channel subsections were numbered 5A and 6A, and the South Channel subsections 5B and 6B. The total number of sections, then, became 31. The volumetric data on these divided sections were recalculated, as given in Table I, and the scaled model dimensions as shown in Table II.

In the model this modification gave the opportunity of isolating the two important channels. To approximate the conditions obtaining in nature, flow between the North and South Channels was permitted at a point above medium tide.

Because 12 in. was set as the full range of MHHW to MLLW, and because it was felt to be more realistic to operate in the MHW to MLW range,

TABLE II.—Scaled Dimensions of Tanks Comprising Model of Grays Harbor and the Chehalis River

Section No.	Volume (cu. in.)		Depth (in.)		Horizontal Dimensions (in.)
	Tidal	Static	Tidal	Static	
1, 2, 3	31,178	28,067	12	10.8	—
4	6,232	4,028	12	7.76	22.79 × 22.79
5	2,349	1,952	12	9.97	14 × 14
6	1,120	1,056	12	11.32	9.66 × 9.66
7	617	1,127	12	21.93	2 × 25.7
8	330	695	12	25.27	2 × 13.75
9	924	929	12	12.06	2 × 38.5
5A	781	1,074	12	16.52	3 × 21.66
5B	1,536	737	12	5.76	5.91 × 21.66
6A	508	751	12	17.75	3 × 14.1
6B	617	296	12	5.76	3.65 × 14.1

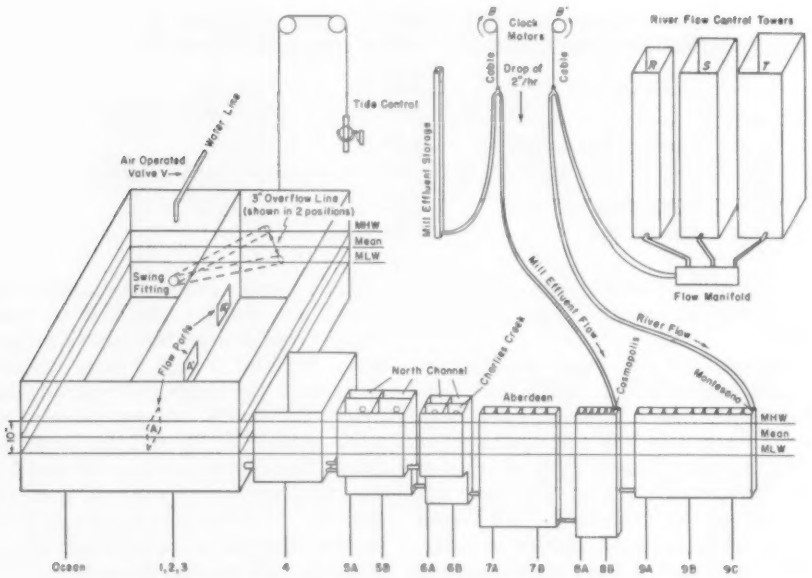

FIGURE 3.—Schematic layout of tide simulator.

the tidal amplitude was reduced from ± 6 in. (above and below medium) to ± 5 in. This 10-in. amplitude approximates the MHW–MLW range, when the MHHW–MLLW range was scaled to 12 in.

A schematic diagram of the system is shown in Figure 3. Free flow from the "ocean" to Sections 1, 2, and 3 was permitted by large openings near the bottom of the partition. Flow from tank to tank was through 1-in. rubber tubing, all situated well below the MLLW level.

Tidal ebb and flow were simulated as follows: A moveable overflow pipe was attached to the "ocean" by means of a swing fitting, well below the MLLW level. The free end of this overflow pipe moved vertically between the MLW and MHW levels in 30-min. cycles. The mechanism actuating this movement was an arm revolving at two revolutions per hour. A cable from the overflow pipe, run over pulleys, was fastened to the arm at a point 5-in. from the center of rotation. Thus, when the tidal control mechanism was turning (at 2 r.p.h.) the overflow pipe raised and lowered through a 10-in. elevation difference in 30 min. When the overflow reached its lowest point a cam on the tidal control mechanism closed a contact switch, which permitted an air-operated valve, V, to open. The "ocean" was so filled during the rising tide—any excess water added overflowed to the sewer—and the tidal rise was carried back through the entire system to the end tank at 9C. When the overflow line reached MHW, the contact switch opened and so closed valve V. As the overflow pipe fell during the ebb part of the cycle, the water from the "ocean" was spilled and the effect of a falling tide carried back to the end tank at 9C.

To simulate the flow of the Chehalis River a series of three tanks (R, S, and T) was built. These tanks were connected through a manifold so that the flow from any one, two or all three could be utilized. To control the flow uniformly a line from the manifold was led to a U-tube having an open,

vertical leg to act as a syphon break. This U-tube was supported by a cable, which in turn was wound on a drum operated by a synchronous clock motor. The diameter and speed of the drum were such as to lower the U-tube 2-in. per hour. Thus, a constant flow, irrespective of the head, was maintained through the "river flow" tube to Section 9C of the river system. These three tanks were calibrated for flow rate and found to give scaled flows corresponding to 687, 1,539, and 1,773 c.f.s. Therefore, by the proper combination of tanks the following "river flows" were possible:

Flow (c.f.s.)	Tank
3,999	R + S + T
3,312	S + T
2,226	R + S
1,539	S
687	R

These "river flow" towers were 4½ ft. high, thus permitting operations to continue for longer than 24 hr. before refilling.

In nature, of course, salt water flows in from the ocean and fresh water from the rivers. A salt gradient is thus established, from 100 per cent salt water at the ocean to 100 per cent fresh water somewhere in the river system. The distance to which this salt gradient extends up-river depends on the flow of fresh water, and on whether the tide is ebbing or flowing. Because of the relatively large volumes of water involved in the model and of the difficulty of maintaining constant salinity, it was felt to be expedient to reverse the flow of salt water. That is, fresh water flowed in from the "ocean" and salt water, equivalent in salinity to sea water, came in as "river flow." By sampling at certain selected "stations" in the system and determining the chloride content of the water at these stations, a fresh water gradient from the ocean upstream to Montesano was calculated.

These gradients for various river flows are shown in Figure 4. The dotted lines show the salinity gradients reported by the State of Washington for conditions of low river flow (about 700 c.f.s.) From Station 9C downriver to about station 7B the data from the model show excellent agreement with those obtained in the natural system itself. It will be noted that below Station 7B, the model salinity gradients become somewhat higher than the natural values; that is, more "salt water" is shown between Stations 7B and 4.

It should be pointed out that in the natural system there are several streams (fresh water) entering the system which are not simulated in the model. Some of these, such as the Wishkah and the Hoquiam Rivers, have fairly large flows—the former varies from 40 to more than 100 c.f.s., and the latter from 7 to 37 c.f.s. This flow would have the effect of depressing the natural salinity gradient to some extent.

The determination of the distribution of the effluent from a mill sewer outfall was carried out in a manner as follows. A tower and flow control mechanism similar to that described for the river flow was made, the tower having such an area that a 2-in.-per-hour fall in level corresponded to 31 c.f.s. flow (that is, 20 m.g.d.).

The solution used was a solution of ferrous ammonium sulfate having an iron content of 10,000 p.p.m. By a simple colorimetric determination (2), the quantitative distribution of this metal could be determined at any of the stations described. These concentrations were calculated as dilutions; that is, the ratio of the concentration of the metal in the mill effluent storage to the concentration at the station determined. Using such dilution factors the data obtained were generally applicable to any loading a mill sewer of given capacity might carry.

An extension to the study was made in which a larger tower was used, giving an equivalent scaled flow of 37 m.g.d.

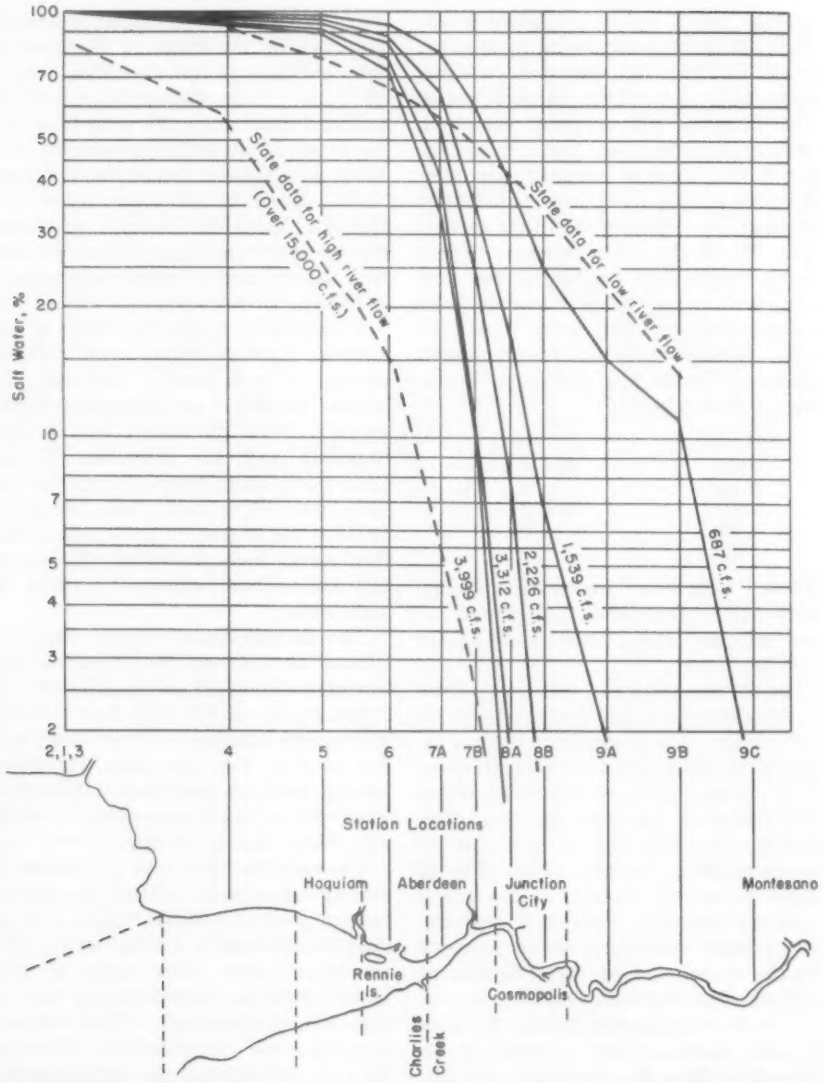

FIGURE 4.—Salinity gradient for Grays Harbor and various Chehalis River flows.

Distribution and Concentrations of Effluents

The studies described in the following were confined to the periods of low river flow. In nature, during the month of May, flows of fresh water in the Chehalis system became relatively low (less than 4,000 c.f.s.). Studies of the data reported in the U. S. Geological Survey Water Supply Papers have shown that these river flows progressively decrease to an average monthly value of about 900 c.f.s. and, further, that the actual daily flows may become lower than 750 c.f.s. for extended periods. Since this change of flow is a

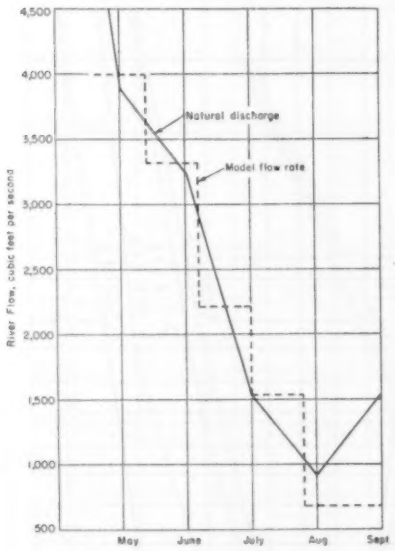

FIGURE 5.—Discharge rates of natural and model rivers.

continuous phenomenon and probably prevents the natural system from ever reaching an equilibrium, it was felt that the model studies should be based on a river flow that was being continuously reduced.

In Figure 5 the solid line shows the average monthly discharge rate of the Chehalis system from May to September. The schedule of flows used in the model is shown in the same figure (broken line). As indicated, 24 "days" (24 hr. of actual time) or 48 tidal cycles were run at 3,999 "c.f.s." and then the flow was reduced to 3,312 "c.f.s." After 24 "days" the flow was reduced again to 2,226 "c.f.s." and allowed to run for 24 "days." In this manner, through four step-wise reductions in flow, a flow of 687 "c.f.s." was finally arrived at.

Preliminary check tests showed that virtual equilibrium would be attained in something less than 10 "days." All the data reported herein are based on tests of approximately 24 "days" of constant "river flow." The various "stations" were sampled at mean tide following high tide.

The various conditions investigated are enumerated and the results are graphically shown in accompanying figures. The detailed data on which these charts are based are so voluminous they are not included.

An outline of the studies made is as follows:

1. Mill outfall at Cosmopolis
   (a) Continuous discharge, 300-ton-per-day mill (Figure 6).
   (b) Intermittent discharge (on ebbing tide) 300-ton-per-day mill (Figure 7).
2. Mill outfall at "Charlies Creek"
   (a) Continuous discharge, 300-ton-per-day mill (Figure 8).
   (b) Intermittent discharge (on ebbing tide) 300-ton-per-day mill (Figure 9).
   (c) Continuous discharge, 550-ton-per-day mill (Figure 10).

These data were all calculated as dilution factors, where

$$\text{Dilution factor} = \frac{\text{Conc. (p.p.m.) in mill sewer}}{\text{Conc. (p.p.m.) in bay at point of test}}$$

This factor is independent of the sewer loading, but is inversely proportional to the rate of discharge of the sewer. That is, doubling the rate of discharge (by, for instance, doubling the mill production capacity) will halve the dilution factor if the concentration of the loading in the mill sewer remains unchanged.

Results and Conclusions

As previously indicated in the outline of the studies made, the data obtained were on the basis of dilution factors and are presented as Figures 6, 7, 8, 9, and 10. To summarize these data and present them on a somewhat more familiar basis, Figures 11, 12, 13,

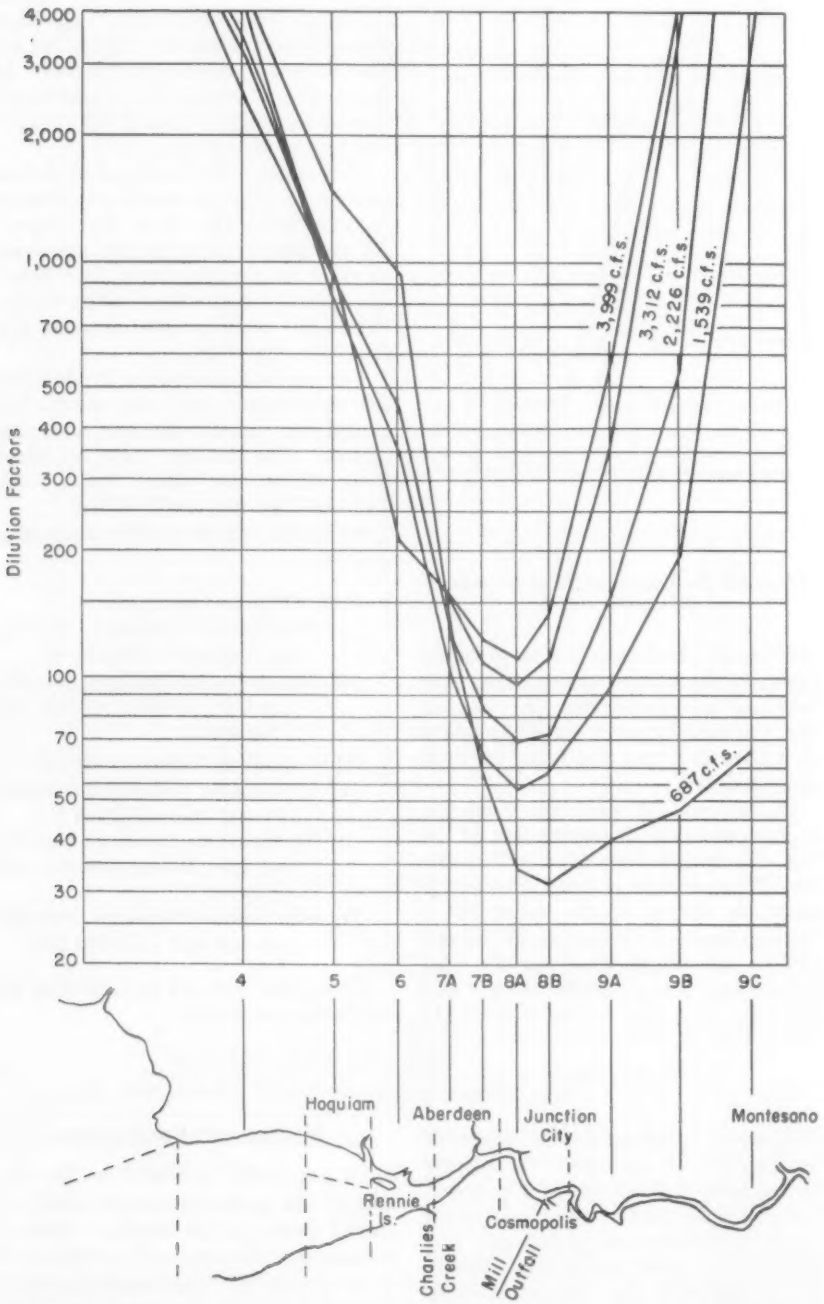

FIGURE 6.—Dilution factors for 300-ton-per-day mill with outfall at Cosmopolis, discharging continuously.

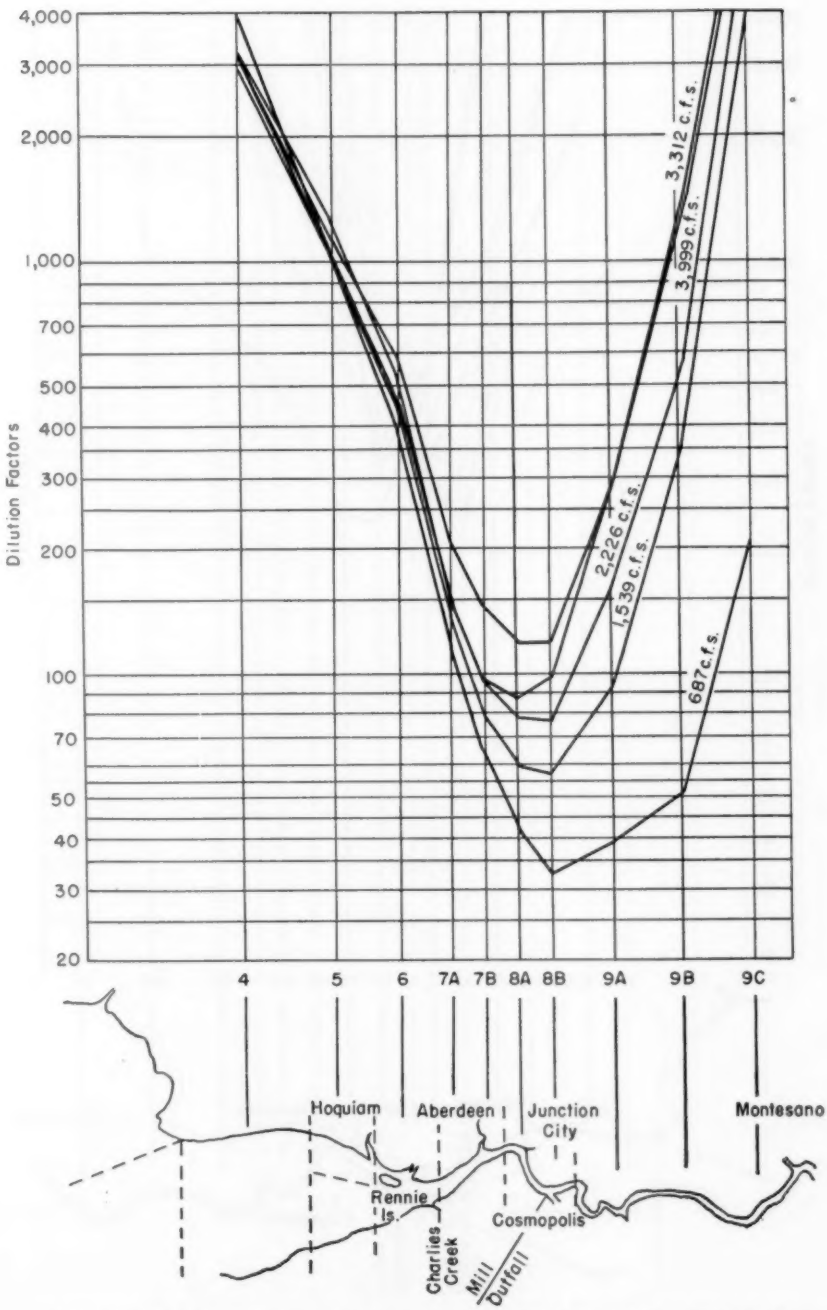

FIGURE 7.—Dilution factors for 300-ton-per-day mill with outfall at Cosmopolis, discharging intermittently.

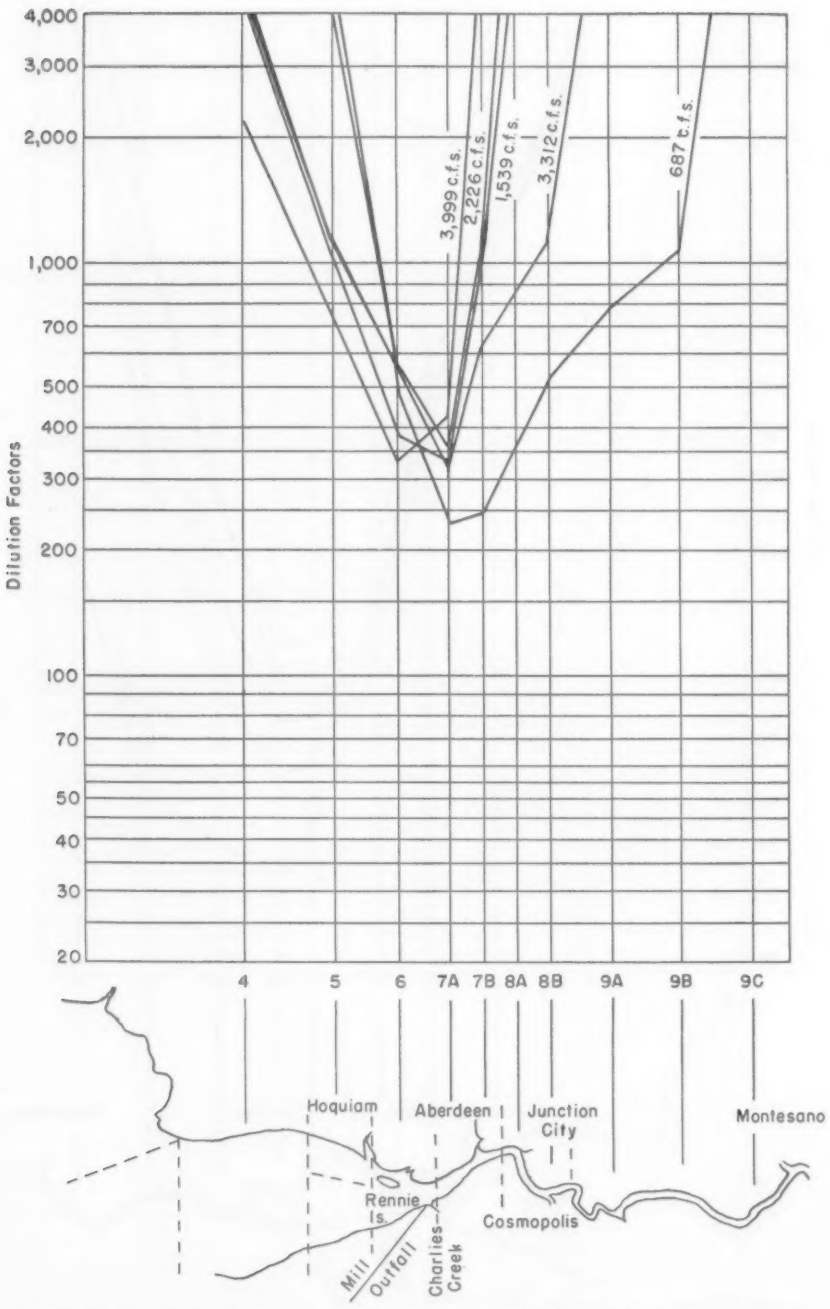

FIGURE 8.—Dilution factors for 300-ton-per-day mill with outfall at Charlies Creek, discharging continuously.

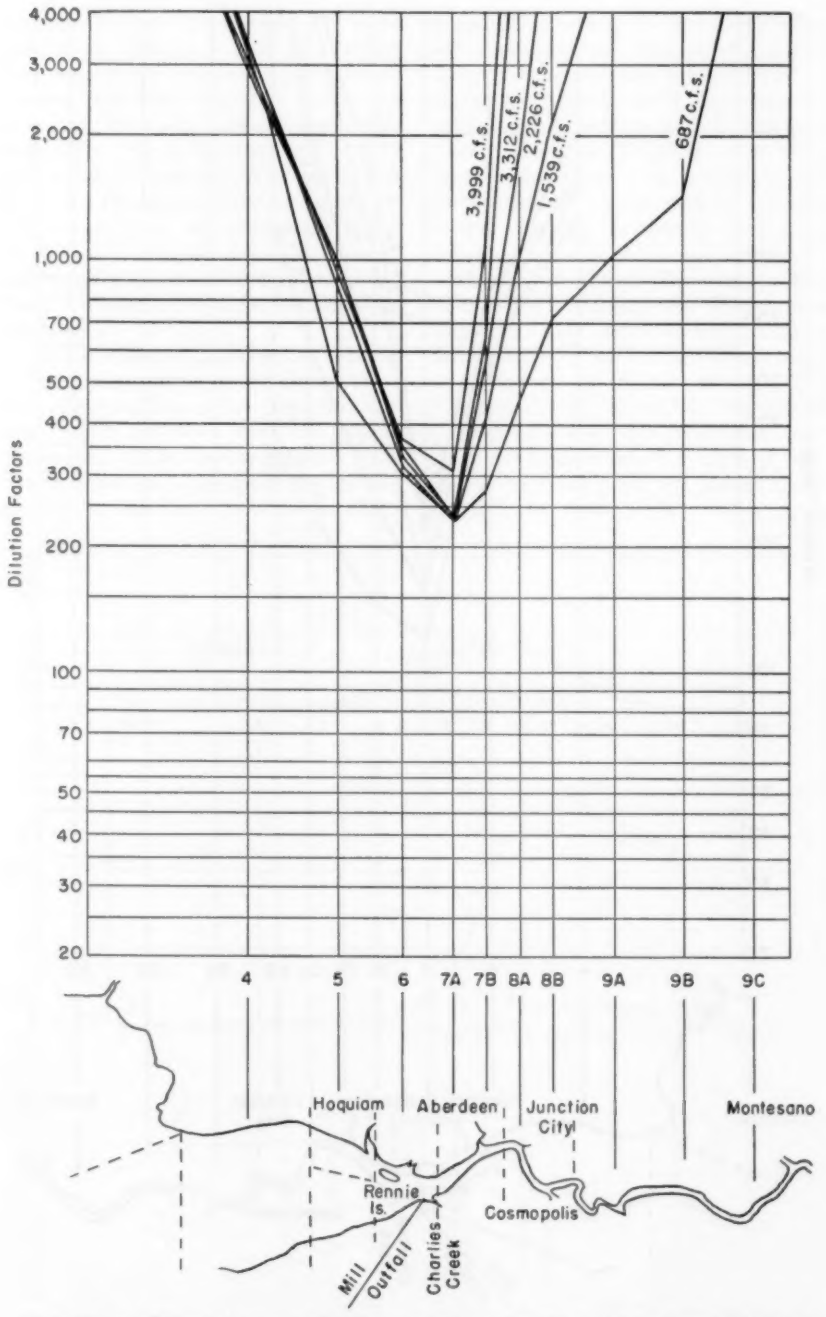

FIGURE 9.—Dilution factors for 300-ton-per-day mill with outfall at Charlies Creek, discharging intermittently.

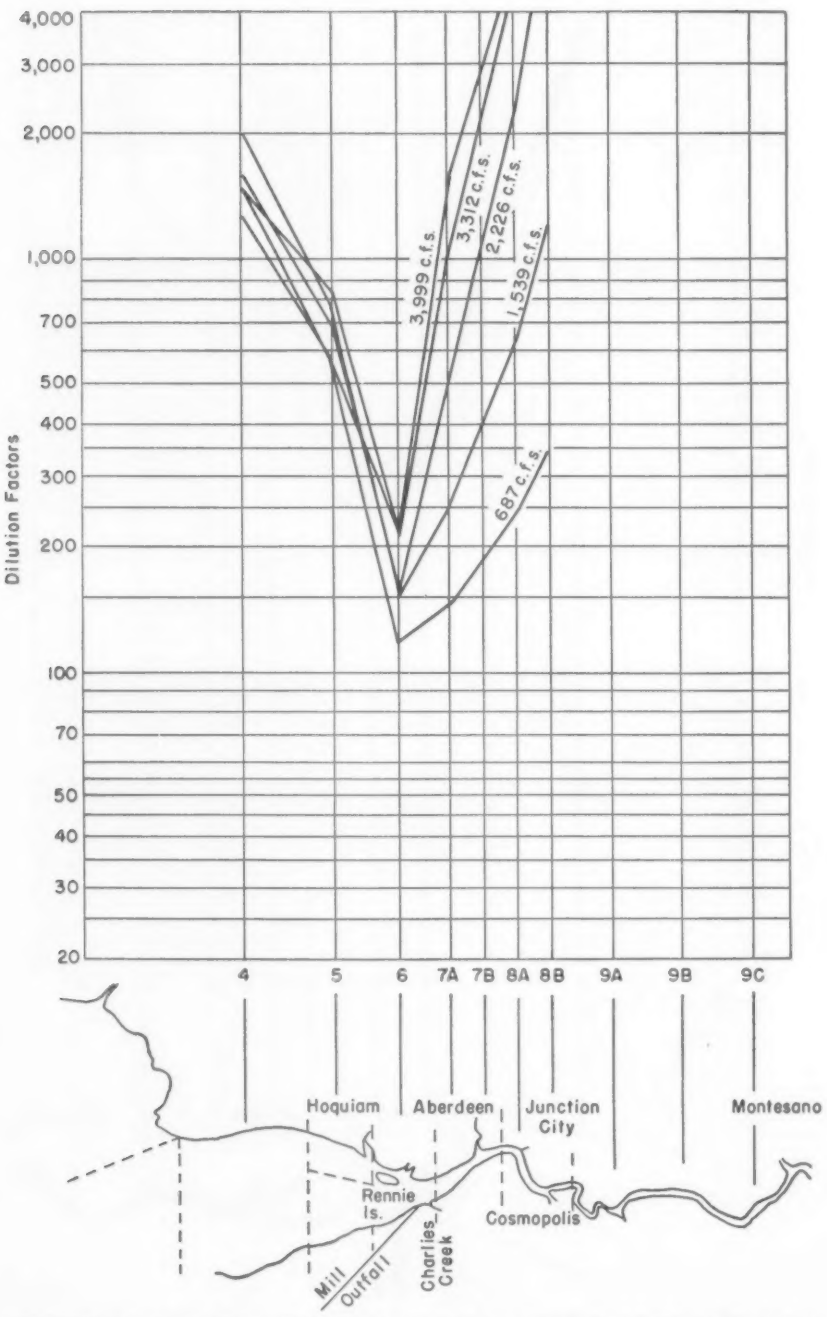

FIGURE 10.—North Channel dilution factors for 550-ton-per-day mill with outfall at Charlies Creek.

14, and 15 were prepared. In these figures an arbitrary unit of loading was used as the ordinate. The unit of loading selected was 100 p.p.m. of B.O.D. Thus, in considering these data, if a sewer loading ran to 225 p.p.m., all the data would be multiplied by 2.25. Or again, if the loading were 375 p.p.m. then the multiplier would be 3.75. It was felt that the data so presented would be of more general use than if a constant B.O.D. loading were assumed.

Figure 11 shows the effect of location of the sewer outfall on the distribution and concentration in the bay-river system. With low river flows the change in location of the discharge point from the mill site at Cosmopolis to the bay proper, at Charlies Creek, shows about a six-fold decrease in maximum effluent concentration. Also, the effluent of up-river concentration is even less. At higher river flows (4,000 c.f.s.) the advantage of relocation is less, but still shows about a 3½-fold reduction. These results are what might be expected from a consideration of the funnel analogy presented earlier in this paper.

Figure 12 shows the comparative effects of discharging the effluent continuously and intermittently (on a falling tide) when the discharge point is located at (a) Cosmopolis and (b) Charlies Creek. These data are shown for conditions of low river flow only. Any advantages of one type of discharge over the other are almost insignificant at Cosmopolis. There is a

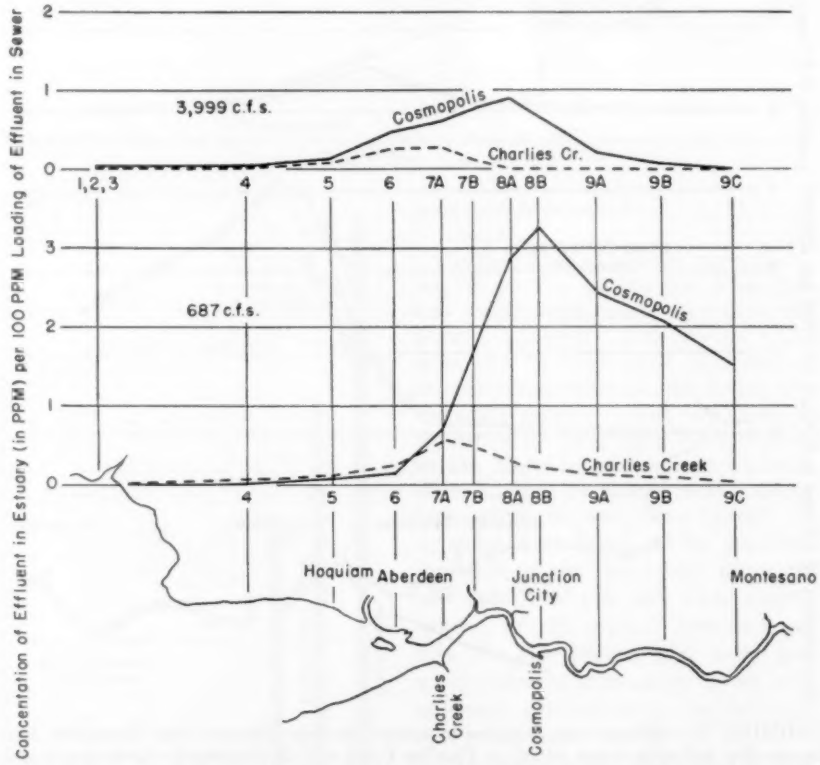

FIGURE 11.—Effluent concentration in estuary for two different river flows with 300-ton-per-day mill with sewer outfall at Cosmopolis and at Charlies Creek.

slight advantage for intermittent flow at the point of discharge at Charlies Creek.

Figure 13 shows the comparative concentrations for mills of different sizes. In the model 300- and 550-ton per-day capacities were simulated. From the data on these two sizes the effects of the discharge from a 400-ton-per-day mill were calculated (dotted line, Figure 13). These data were based on a mill outfall at Charlies Creek during low river flow periods. As might be expected, the effluent concentration is directly proportional to the daily mill production.

Figure 14 is an attempt to picture the concentration maxima which might be expected in the North Channel during periods of low river flow, for mills of different production capacities at two outfall locations. From Figure 14 it can be seen that the units of B.O.D. loading per 100 tons of production capacity are as follows:

Discharge at Cosmopolis
1.040 units per 100 tons
Discharge at Charlies Creek
0.152 units per 100 tons

In other words, shifting the discharge point from Cosmopolis to Charlies Creek should lower the magnitude of

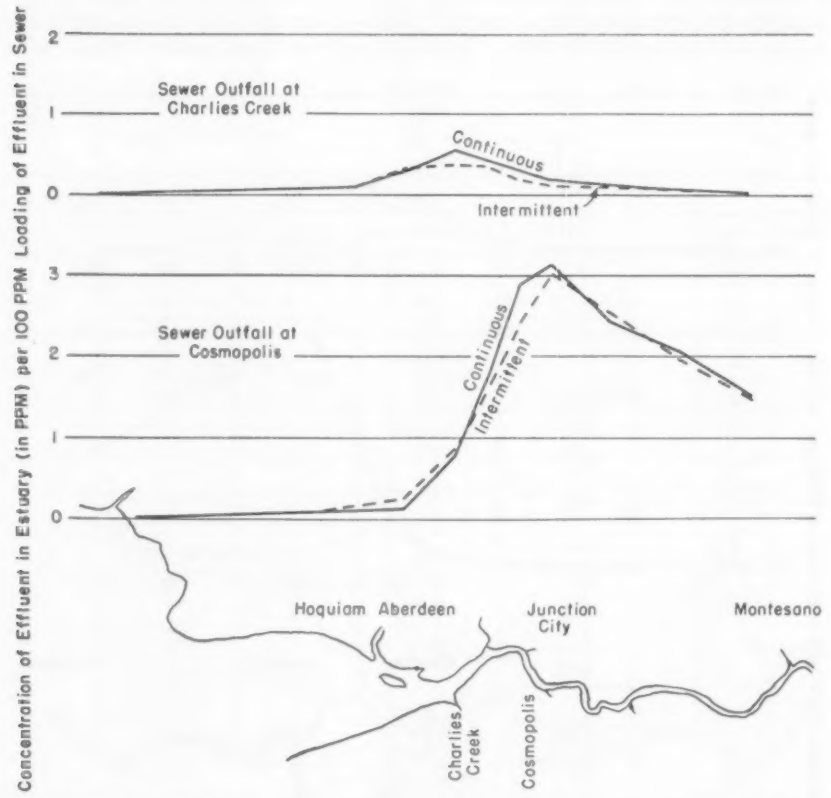

FIGURE 12.—Effluent concentration in estuary for two different river flows with 300-ton-per-day mill with sewer outfall at Charlies Creek and at Cosmopolis continuously and intermittently (on falling tide) under conditions of low river flow (687 c.f.s.).

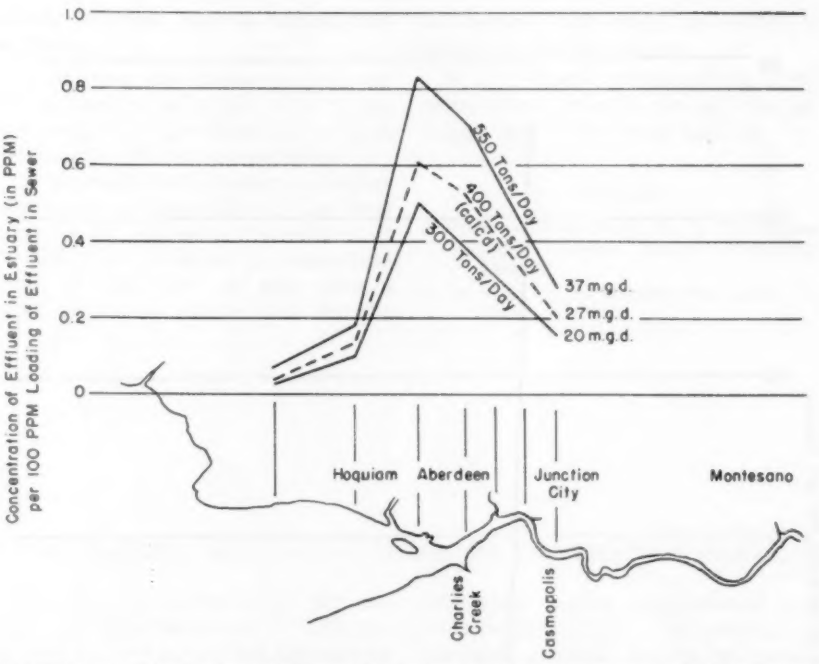

FIGURE 13.—Distribution of effluents for various sizes of mills; sewer outfall located at Charlies Creek; river flow, 687 c.f.s.

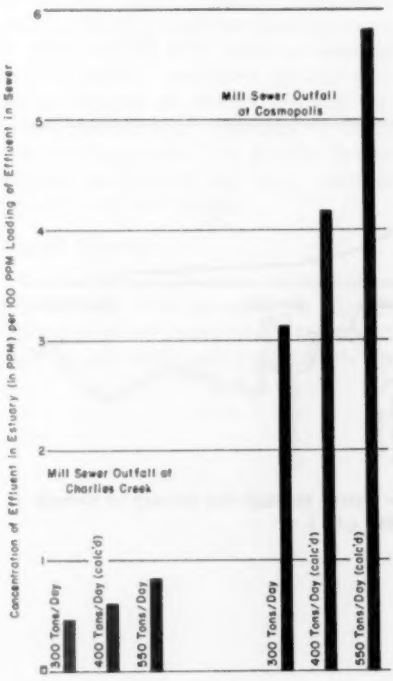
Concentration of Effluent in Estuary (in PPM) per 100 PPM Loading of Effluent in Sewer
Mill Sewer Outfall at Cosmopolis
Mill Sewer Outfall at Charlies Creek
300 Tons/Day
400 Tons/Day (calc'd)
550 Tons/Day
300 Tons/Day
400 Tons/Day (calc'd)
550 Tons/Day (calc'd)

FIGURE 14.—Maximum concentrations of effluents in North Channel for three mill sizes at two outfall locations.

maximum concentration by 1.040/0.152 = 6.8-fold.

Figure 15 is a calculated curve showing the dilution capabilities of the system under what might be called the worst conditions. It shows the minimum flow of new water available at various points in the system during low river flow seasons. Thus, in the upper reaches of the river the new water must be the discharge rate of the Chehalis River at that particular time. Going down river, the new water brought in by tidal flow begins to be effective. However, in the river itself this tidal new water is of relatively small significance. At the point of breaking out into the bay proper, this tidal new water becomes increasingly great and, of course, approaches the full tidal volume at the bar.

The results of the model studies, pre-

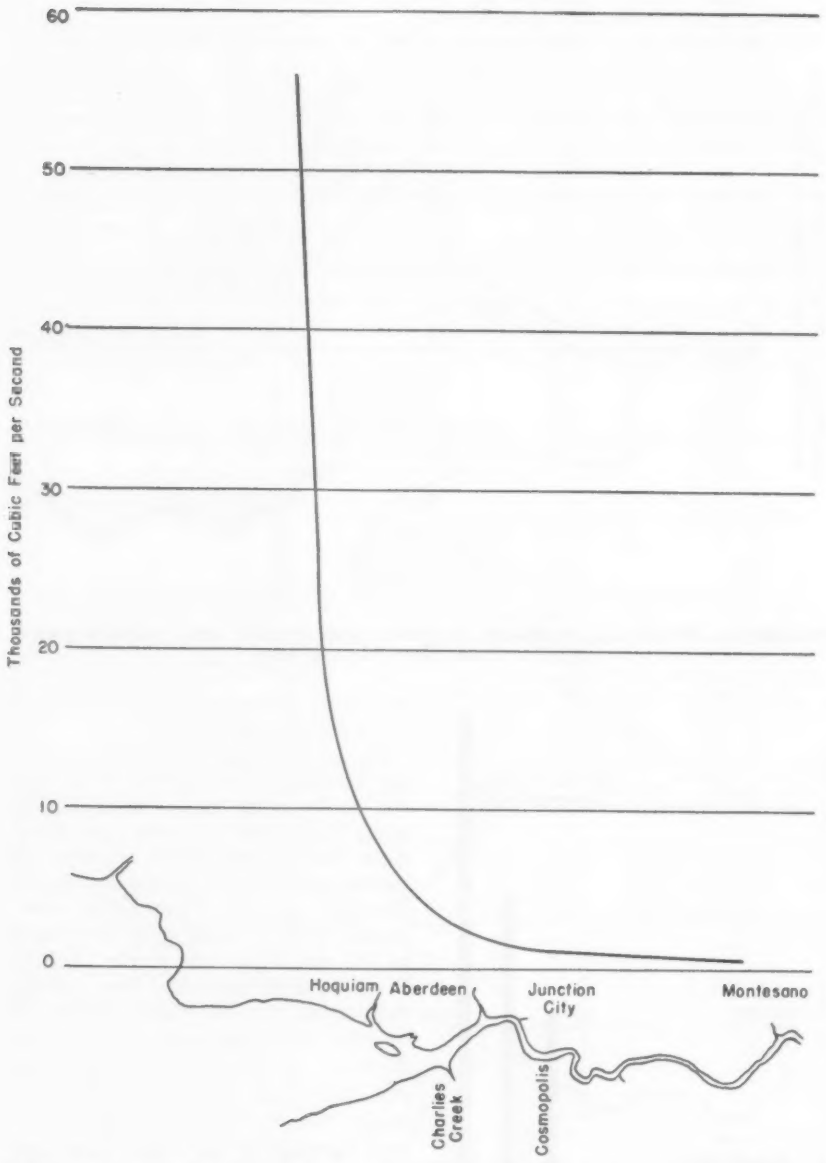

FIGURE 15.—Effective flow of "equivalent new water" through the estuary at periods of low river flow (687 c.f.s.).

viously detailed, may be summarized as follows:

1. Shifting the discharge point of the mill sewer out of the river to the bay proper will give about 6- to 7-fold decrease in effluent concentration.

2. The method of discharge (whether continuous or intermittent) has little effect on the degree or distribution of the effluents, except at the immediate point of discharge. At this point a small advantage can be seen for the intermittent type when the outfall is located in the bay proper.

3. The effluent concentration is directly proportional to the mill tonnage output, and to the sewer loading.

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1956 SECOND AND THIRD QUARTER CONTRACT AWARDS

Construction contracts for the second and third quarters of 1956 approached a new record for the number and value of stream pollution abatement projects awarded by municipalities of the United States. Contracts awarded during the first three quarters of 1956 totaled 600, with a value of $282.5 million, compared to 749 contracts, valued at $200.9 million, reported for all four quarters of 1955.

According to the U. S. Public Health Service the second and third quarter reports were as follows:

Second Quarter

Contracts for 240 projects, valued at $82 million, were awarded to finance 124 projects for new sewage treatment plant construction and 116 projects for interceptor sewers, enlargements, and other related work. The number of contracts awarded during the period was greater than during any of the five previous quarters, and largest in value, except for the first quarter ($129.1 million).

Third Quarter

The number and value of contracts awarded for the third quarter were less than for the second quarter, but continued at a high level. Contracts for 191 projects, valued at $78 million, were awarded to finance 91 projects for new sewage treatment plant construction and 100 projects for interceptor sewers, enlargements, and other related work.

AEROBIC FERMENTATION STUDIES OF SPENT SULFITE LIQUOR

By Herman R. Amberg and James F. Cormack

Research Specialist and Research Chemist, respectively, Central Research Department, Crown Zellerbach Corporation, Camas, Wash.

The sulfite industry has been faced for many years with the important problem of waste disposal. Although many solutions have been proposed, no universal method of waste disposal has been adopted by the industry as a whole. A solution which may be applicable to one operation cannot necessarily be translated to the industry as a whole due to differences in size, economics, and process variables unique to each unit.

Numerous attempts have been made to treat spent sulfite liquor by conventional sewage treatment devices (1) (2) (3) (4) (5). In general, however, these methods would necessitate the construction of a plant which would dwarf the pulp mill. Because of the voluminous quantities of waste water and the difficulty involved in treating such a concentrated material, the problem has not lent itself to normal sewage treatment methods. For example, a 200-ton sulfite mill would discharge a B.O.D. load of about 100,000 lb. per day. At a B.O.D. load of 0.1 lb. per cubic foot of aeration capacity per day, approximately one million cubic feet of aeration capacity would be required to treat this waste by the activated sludge process.

To be successful, activated sludge treatment or a modified activated sludge treatment would necessitate loadings of 2 lb. of B.O.D. per cubic foot of aeration capacity per day. Although this loading appears to be extremely high and unattainable, experience from the fermentation industry has shown that loadings in excess of 2 lb. per cubic foot per day are routine. For example, in the torula yeast fermentation of spent sulfite liquor B.O.D. loadings in excess of 4 lb. per cubic foot per day are employed with resultant B.O.D. reductions of 60 to 70 per cent (2) (6).

An investigation was initiated by the project of the National Council for Stream Improvement at the Engineering Experiment Station, Oregon State College, Corvallis, Ore., to determine the feasibility of reducing the B.O.D. of spent sulfite liquor by high-rate aerobic biological treatment (7) (8). It was thought that by incorporating some of the methods used in the fermentation industry and in the sewage treatment field, a method of treatment might be developed which would accomplish high B.O.D. reductions. It was decided that a mixed bacterial culture would be more effective in reducing the B.O.D. of the waste than pure cultures of microorganisms, and that an extremely heavy inoculum or cell concentration would have to be carried in the aeration unit.

This paper presents some of the operational and design data obtained from laboratory bench-scale operations as well as some preliminary design data used in the construction of a semi-pilot plant for the biological treatment of spent sulfite liquor. Although this method was developed for the treatment of spent sulfite liquor, its application to other strong industrial wastes high in carbohydrates should not be overlooked.

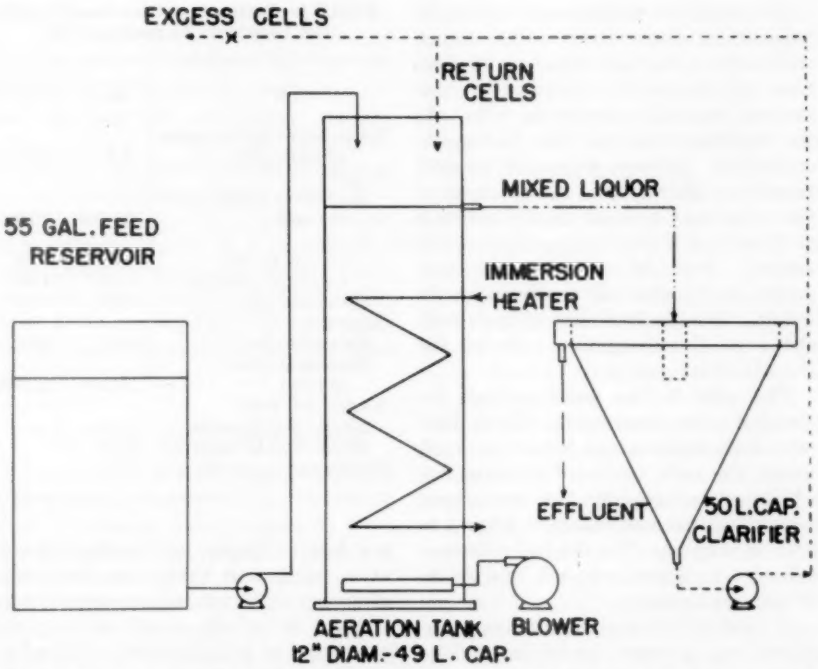

FIGURE 1.—Schematic diagram of the laboratory unit for the aerobic fermentation of spent sulfite liquor.

Laboratory Bench-Scale Experiments

A schematic diagram of the initial laboratory apparatus is shown in Figure 1. Raw ammonia-base spent sulfite liquor was pumped by a constant displacement pump from a 55-gal. storage tank to the aeration tank, where it was aerated in the presence of bacterial cells. Six 1-in. diameter (3 in. long) carborundum diffusers were used to supply air, an excess of air being supplied at all loadings. The aerator was heated to 35° C. by means of a stainless steel immersion heater controlled by a thermostat. The aeration volume was maintained at 49 l.

The mixed liquor discharged by gravity to a conical settling basin (50 l. capacity) where the cells were separated from the supernatant liquor. The effluent passed over the overflow weir of the clarifier and was discharged to the sewer. The settled cells were pumped back to the aeration chamber, and once each day the excess cells which accumulated in the clarifier were withdrawn to maintain a constant concentration of cells in the aeration unit.

The ammonia-base spent sulfite liquor was obtained from an operating mill as digester liquor of 12 per cent solids and a 5-day, 20° C. B.O.D. ranging from 30,000 to 42,000 p.p.m. The liquor was diluted with tap water to give the desired concentration. The raw waste concentration was varied from 0.4 to 8.2 per cent total solids. The spent liquor was neutralized to a pH of 7.0 to 7.4 with sodium carbonate and supplemented with phosphorus to insure a B.O.D. to phosphorus ratio of 60 to 1. Nitrogen was not required because the spent liquor contained 0.2 lb. of ammonia per pound of B.O.D. Anti-foam emulsion was added to the raw feed to reduce foaming.

The bacterial culture was started by inoculating dilute spent sulfite liquor with river water and allowing the bacteria to increase in numbers by continually returning the excess cells. As the bacteria increased, the waste concentration fed was increased proportionally. Microscopic examination of the organisms present in the aeration tank indicated that the population was entirely bacterial and no protozoa, yeast, or filamentous organisms were noted. The predominant culture consisted of Gram-negative rods of the *Pseudomonas* group.

The cells in the aeration unit resembled a clay suspension. Upon dilution with supernatant liquor or wash water, the cells coalesced to form floc which settled rapidly. A 4-per cent cell suspension was obtained after 4 to 6 hr. of settling. The washed cells contained 4 to 8 per cent ash and 66 to 74 per cent protein.

A total of 10 experiments was conducted using waste containing sulfur dioxide, and one experiment was conducted using sulfur dioxide-free waste. A summary of the results is presented in Table I.

The suspended solids content was varied from 10,000 to 32,000 p.p.m., and high B.O.D. reductions were obtained at all cell concentrations. Using waste containing sulfur dioxide, excellent results were obtained up to a waste concentration of 8.5 per cent, and at 9.0 per cent total solids failure resulted. Removal of sulfur dioxide by lime precipitation improved treatment results, and a 12 per cent digester-strength waste could be treated with resultant B.O.D. reductions of 84 per cent at a B.O.D. load of 2.58 lb. per cubic foot per day. It is of interest to note that raw waste having a B.O.D. of 39,000 p.p.m. could be treated readily when carrying 22,000 p.p.m. of suspended solids.

The amount of oxygen that had to be supplied to a culture with 20,000 p.p.m. suspended solids was 428 p.p.m. per hour. Employing mechanical aeration equipment having an absorption efficiency of 23 per cent, approximately 104 cu. ft. of air would be required per pound of B.O.D. added, or 36 c.f.m. of air per ton of pulp produced. The power cost per ton of pulp would then be about $0.80. When treating ammonia-base liquor the only nutrient required was phosphorus. About 8 lb. of phosphorus and 15 lb. of ammonia (for neutralization of the steam-stripped liquor) were required per ton of pulp.

It was estimated that the approximate cost of conducting this treatment process would be about $5.00 to $8.00 per ton of pulp produced. It becomes evident that this process would place an excessive economic burden on the pulp mill. To be successful some economic return must be realized from the process. Analyses of the bacterial cells produced in the fermentation process showed that they contained 66 to 70 per cent protein. Complete amino acid and vitamin assays (8) showed that the material possibly could be utilized as a high-protein animal feed. There is a good possibility that this by-product could be developed into a high-

TABLE I.—Summary of Operational Results from Laboratory Fermentation Unit

Item	Unstripped Waste	SO_2-Free Waste
Solids, spent sulfite liquor strength (%)	8.2	12.0
B.O.D.:		
Raw spent sulfite liquor (p.p.m.)	20,700	39,000
Load:		
Lb./cu. ft./day	1.61	2.58
Lb./lb. of cells/day	1.22	1.88
Reduction (%)	79.5	84.0
Aerator:		
Retention (hr.)	19.2	22.6
Suspended solids (p.p.m.)	21,100	22,000
Washed cell yield:		
Lb./lb. B.O.D. added	0.40	—
Lb./lb. B.O.D. removed	0.50	—
Protein content of cells (%)	65.5	—

protein animal feed which could be sold; thus defraying to some extent the treatment cost. Whether or not this could be done profitably would depend on the cost of production, market prices, etc. At best, the operation would be expected to be marginal due to the competitive nature of the protein feed market. In addition, before this material would be accepted as a high-protein animal feed, two or three years of experimental feeding would have to be conducted to be absolutely certain that the material had no toxic effect on animals.

Semi-Pilot Plant Experiments

The success of the initial laboratory experiments resulted in the construction of a larger unit (Figure 2) from which design data could be obtained for a full-scale plant installation.

Although fermentation in the initial experiments was conducted without removal of sulfur dioxide, experimental results showed that considerable savings were affected by sulfur dioxide removal. In addition to higher loadings, sulfur dioxide removal resulted in a 50 per cent reduction in the quantity of neutralization chemicals used, and a small saving through the recovery of sulfur which can be re-used in the pulping operation. Sulfur dioxide removal was conducted in an 8-in. diameter by 18 ft. stainless steel column. The raw liquor was pumped through a preheater and then admitted at the top of the stripping column. The hot liquor was passed countercurrent to the steam through a bed of ½-in. Raschig rings, a total of 4 cu. ft. of packing being used in the column. Sulfur dioxide removal was essentially complete at feed rates of 37 g.p.h.

Because of the high oxygen requirements, mechanical aeration equipment was used. A shrouded, 9-in. diameter turbine was driven by a ½-h.p. variable speed motor. Air was admitted to the turbine and dispersed in the fermenting solution. To eliminate excessive foaming, an 8-in. diameter draft tube was placed in the center of the fermentation tank, and the foam-liquid

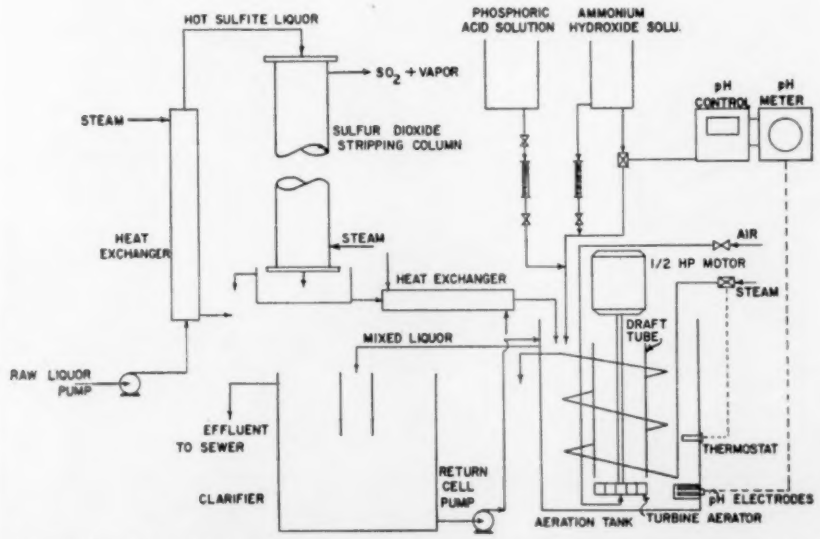

FIGURE 2.—Flow sheet of semi-pilot plant for aerobic fermentation of spent sulfite liquor.

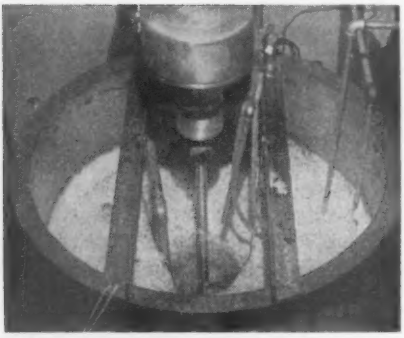

FIGURE 3.—Circulation of liquor in fermentation tank.

mixture was recirculated through the draft tube from top to bottom by means of the turbine agitator (Figure 3). This type of aeration system was originally used in the torula yeast fermentation process in Germany during World War II and is presently being used by the torula yeast producers in the United States (2). Essentially, fermentation was conducted in a foam-liquid phase; equilibrium was established by means of the draft tube. The fermentation tank contents consisted of a 2 to 1 mixture of foam and liquid. Fermentation volume was maintained at 63.3 gal.

The semi-pilot plant is shown in Figure 4. Raw calcium-base spent sulfite liquor, containing about 10 per cent total solids was pumped by a stainless steel positive displacement pump to the steam-stripping column. The steam-stripped liquor passed to a constant head tank and was metered by means of a needle valve and rotometer into the fermentation tank. Ammonium hydroxide and phosphoric acid were similarly metered into the

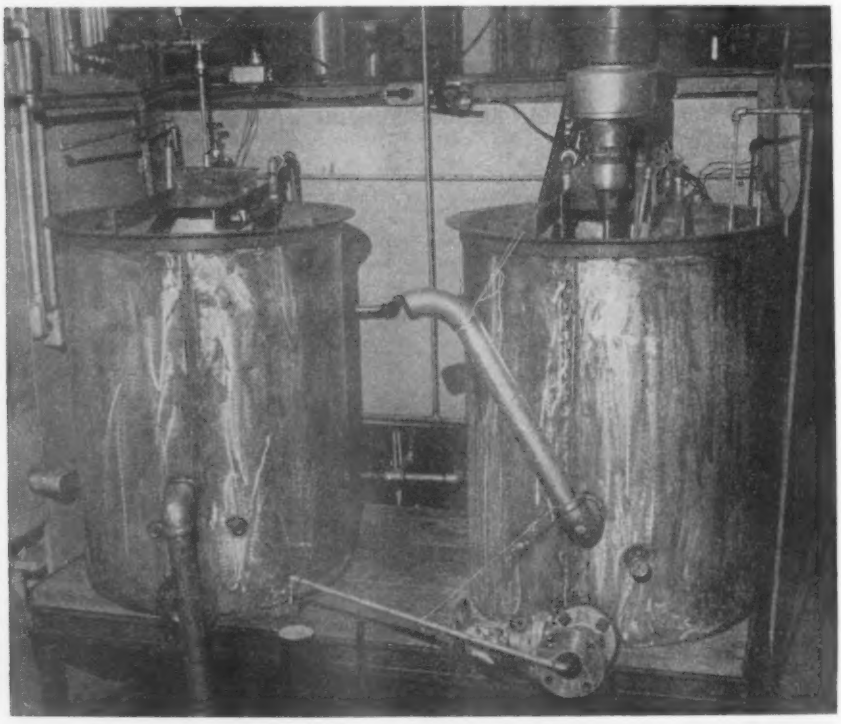

FIGURE 4.—Semi-pilot plant setup.

fermentation tank to supply the nutrient requirements of the bacterial culture. Automatic pH control was employed to maintain a balance at 7.0. The air supply was controlled by means of a rotometer and needle valve.

The mixed liquor from the aeration tank flowed by gravity to a settling tank where separation of bacterial cells and fermented liquor occurred. The settled cells were returned to the aeration unit by means of a pump. Daily withdrawals of cells maintained a constant cell concentration in the aerator.

To date, insufficient data have been collected to present experimental results. However, from initial observations it appears that results obtained on a smaller scale can be duplicated successfully by the intermediate-size plant described and it may be possible to exceed loadings and yields obtained in the laboratory bench-scale operations.

Summary and Conclusions

An aerobic fermentation process, capable of reducing 80 to 90 per cent of the B.O.D. of spent sulfite liquor, was developed by employing a mixed bacterial culture. The process, a modification of the activated sludge process, uses a heavy inoculum of 20,000 to 30,000 p.p.m. of suspended solids and is operated at B.O.D. loadings in excess of 2 lb. per cubic foot of aeration capacity per day. Raw spent liquor having a B.O.D. of 39,000 p.p.m. was successfully treated at a B.O.D. load of 2.6 lb. per cubic foot per day, when carrying 22,000 p.p.m. of suspended cells in the aeration unit. The B.O.D. reductions at this load were 84 per cent, and cell yields of 0.5 lb. per pound of B.O.D. removed were attained. The bacterial cells contained 66 to 70 per cent protein and were found to contain most of the essential amino acids in relatively high concentration.

Based on the initial bench-scale laboratory experiments a semi-pilot plant was designed to treat 112 g.p.d. of digester-strength spent sulfite liquor. The treatment or fermentation plant consists of a steam-stripping column for removal of sulfur dioxide; a fermentor equipped with mechanical aeration equipment, using a turbine-type mixer and a draft tube to prevent excessive foaming; a sedimentation tank for separation of bacterial cells and treated waste; and a recirculation pump for return of cells to the fermentor. Compressed air is admitted to the turbine mixer and dispersed into the fermenting mixture composed of equivalent volumes of foam and liquid.

Although this method of treatment has been successfully operated on a laboratory scale, there are many process variables which can only be determined from a pilot-plant operation. The importance of an extensive experimental program to determine the nutritional potential of the protein feed should not be overlooked. A modest estimate indicates that a minimum of two to three years of additional study would be required before the process could be considered on a commercial scale.

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8. Amberg, H. R., "The Production of Protein Concentrate Animal Feed from Spent Sulfite Liquor." Proc. Seventh Pacific Northwest Indus. Waste Conf., Washington State College, Pullman, Wash.

MEETINGS OF INTEREST

1957

May 12–17	**American Water Works Association,** Atlantic City, N. J. Harry E. Jordan, Secretary, AWWA, 2 Park Ave., New York 16, N. Y.
May 13–15	**Twelfth Purdue Industrial Waste Conference,** Purdue University, Lafayette, Ind. Professor Don E. Bloodgood, School of Civil Engineering, Purdue University, Lafayette, Ind.
May 18	**Industrial Radiation Conference,** University of Texas, Austin, Texas. Professor Earnest F. Gloyna, University of Texas, Austin 12, Texas.
Jun. 3–7	**American Society of Civil Engineers,** Spring Convention, Buffalo, N. Y. W. H. Wisely, Executive Secretary, 33 West 39th St., New York 18, N. Y.
Jun. 3–14	**37th Congress de l'Association Générale des Hygiénistes et Techniciens Municipaux** (General Association of Hygienists and Municipal Technicians), Madrid, Spain. P. Descroix, Secretary General, 9, rue de Phalsbourg, Paris (17), France.
Jun. 9–12	**American Institute of Chemical Engineers,** Seattle, Wash.
Jun. 17–21	**Bioxidation of Organic Wastes,** Manhattan College, New York, N. Y. Associate Professor W. W. Eckenfelder, Jr., Civil Engineering Dept., Manhattan College, New York 71, N. Y. Special course on theory and design of bioxidation. Fee $100.
Jun. 24–28	**Seventh Annual Pennsylvania Sewage Works School,** University Park, Pa. Clifford V. Smith, Jr., Dept. of Civil Engineering, Pennsylvania State University, University Park, Pa.
Aug. 19–23	**Massachusetts Institute of Technology.** Disposal of Industrial Wastes from the Textile Industry. Summer Session, M.I.T., Cambridge 39, Mass.
Aug. 20–22	**Northwestern University.** Liquid scintillation counting. Associate Professor Carlos G. Bell, Jr., Northwestern University, Evanston, Ill.
Sep. 22–25	**Public Works Congress and Equipment Show,** Philadelphia, Pa. Donald F. Herrick, Executive Director, American Public Works Association, 1313 East 60th St., Chicago 37, Ill.

STATISTICAL INTERPRETATION OF PILOT-PLANT STUDIES

By H. Van Blarigan and James C. Lamb, III

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The Bound Brook plant of American Cyanamid Company manufactures a wide variety of organic intermediates and chemicals for use in the rubber, plastics, and pharmaceutical industries, as well as several hundred dyes and pigments. The industrial waste discharged from this plant consists of a heterogeneous mixture of all process waste waters from the manufacture of more than 800 products, cooling waters, sanitary sewage, and small intermittent flows of storm water. The total volume of flow from all of these sources varies from 10 to 25 m.g.d. and averages about 16 m.g.d. The raw waste has a pH normally between 1.0 and 2.5, and contains coloring materials of varying hues and intensities. Its pollutional strength varied from 150 to 450 p.p.m. of 5-day B.O.D. and averaged 300 p.p.m. during 1955.

In accordance with the program of the New Jersey State Department of Health, the company started systematic studies in 1938 in an attempt to develop a satisfactory treatment process for its wastes. As a result of these studies, a treatment plant was placed in service in 1940. This plant included facilities for equalization, neutralization of acidity to a pH of about 5.0, and settling, with further equalization, in a 60-m.g. lagoon. Intermixing of various colors in the raw waste results in production of a relatively stable pale yellow color in the effluent from the lagoon. Certain features of this plant have been described in earlier articles (1)(2)(3)(4)(5).

The existing treatment plant removes only 5 to 10 per cent of the organic pollutional load. Under present statutory requirements, it is necessary that the B.O.D. of this waste be reduced substantially before discharge into the river. To meet the statutory standards for effluent quality, it is necessary to resort to a biological treatment of waste.

Pilot-Plant Operation

In 1949 preliminary studies were undertaken on a laboratory scale to determine whether the waste was amenable to treatment by conventional biological processes. The data gathered during this investigation indicated that the waste could be treated satisfactorily on trickling filters.

A small pilot trickling filter was installed immediately at Bound Brook for obtaining limited information on the type of performance which could be expected on a day-to-day basis, operating with run-of-the-plant waste. Results from this unit confirmed the opinion that the company would be justified in proceeding with construction and operation of a larger-scale trickling filter pilot plant. The larger pilot units were needed to permit carrying out more precise investigations of this method of treatment for the purpose of arriving at suitable design factors for a full-scale plant. This pilot plant was completed and placed in operation in August, 1953. Individual plant elements and the procedures

followed in their operation have been described in some detail in earlier articles (6)(7)(8)(9).

The waste on which the pilot plant was operated was, insofar as possible, identical to that which would be treated in a full-scale installation. Effluent from the 60-m.g. settling and equalizing lagoon was pumped continuously to the pilot-plant site and aerated to remove carbon dioxide, prior to pH adjustment with lime, and to satisfy the immediate chemical oxygen demand of the waste. Because the pH of this waste was normally about 5.0, it was necessary to provide facilities for automatic and continuous neutralization to a pH of about 7.0 prior to biological treatment. After neutralization, the waste was settled again for removal of additional precipitated materials.

The 20-ft. diameter trickling filter was constructed in accordance with conventional practice. Commercial underdrain blocks were sloped to discharge into a concrete flume through the center of the filter bottom. The 6-ft. deep stone bed was encased in a steel shell, and equipped with a standard reaction-type rotary distributor.

After passing through the trickling filter, the waste was discharged into a conventional circular clarifier for removal of solids. This unit was of sufficient size to treat the combined recirculation and throughput, and was equipped with sludge removal facilities.

Suitable wells, piping, and pumps were included to permit recirculation in several different patterns. Valves and meters were provided for controlling all flows of air, raw waste, recirculation, and sludge.

Operators were kept in attendance for flow adjustments and sampling on a 24-hr., seven-day week basis. Separate laboratory facilities and personnel were assigned exclusively to this program by the control laboratories group of the manufacturing plant, and the services of all plant research and analytical laboratories were available on a cooperative basis. All operations were under the close supervision of sanitary engineers.

Observations in the field by plant operators included temperature, dissolved oxygen, pH, settleable solids, and rates of flow of liquids and air. The influent and effluent from each treatment unit were sampled hourly to make daily composites for laboratory analyses. These analyses included: B.O.D.; C.O.D.; suspended solids; volatile suspended solids; total and volatile solids of sludges, nitrogen, and phosphorus; as well as others. Microscopic examinations of organisms in the filter slimes were made at frequent intervals.

The pilot units previously described were operated continuously from August, 1953 to June, 1955. During this period many modifications of the basic flow diagram for the plant were investigated for the purposes of overcoming special problems in operation and attempting to improve B.O.D. removals through primary and secondary treatment units. Although much valuable information was obtained from these studies, the over-all degree of B.O.D. removal through the plant was disappointing.

Also, during the 1953–55 period it was established that the plant B.O.D. load was much higher than had been anticipated. This factor, coupled with decreased waste volumes resulting from a water conservation program in the manufacturing plant, resulted in the necessity for attaining higher degrees of B.O.D. removal than originally contemplated. Accordingly, it was decided that two-stage trickling filters should be investigated to determine whether this arrangement might prove more satisfactory in a full-scale plant.

In June, 1955 a second 20-ft. diameter trickling filter was placed in operation. This unit was identical with the original filter, with the exceptions

of an 8-ft. stone depth, a peripheral effluent collection channel, and provision for additional ventilation by extension of the underdrains through the filter side walls. Piping and pumps were installed to permit operation of the two units in parallel, or in series with either filter serving as the lead unit. Several periods of parallel operation indicated that equivalent performance was obtained from these two units, with comparable B.O.D. loadings, recirculation ratios, and temperatures.

Between June and December, 1955, the two filters were operated under conditions designed to establish the effects of B.O.D. loading, recirculation ratio, and temperature, with single- or two-stage operation. Daily changes in the strength and character of the influent waste made it impossible to control B.O.D. loadings precisely. The order of magnitude of the B.O.D. loading was varied by regulating the influent flow to the filters, and recirculation was adjusted to maintain a uniform hydraulic loading on the units. Any major changes in operating conditions were carried out gradually, by making small daily changes, to avoid danger of shock loading the units.

Facilities were not available for controlling temperatures of the large flows passing through this plant. Therefore, there was a wide range in operating temperature, which changed slowly over the period June to December. In addition, temperatures of the two units were different by several degrees, on occasion, due to varying amounts of ventilation through the filters and different recirculation ratios. This was true especially during winter months, when there was appreciable cooling of waste passing through the filters.

Collection of Data

The variables usually considered to be of major importance in performance of a trickling filter plant include the following:

1. B.O.D. loading.
2. Recirculation ratio.
3. Temperature.
4. Hydraulic loading.

In laboratory or small-scale pilot-plant studies of trickling filters it is usually possible to control these variables rather closely. However, in a semi-works installation of the size used in these studies, it is extremely difficult to exercise the same degree of regulation. It already has been pointed out that operating temperatures in the plant varied seasonally, and the B.O.D. concentrations and loadings were not subject to precise control, since the filters operated on run-of-plant waste. The remaining two variables—recirculation ratio and hydraulic loading—could be varied at will.

Based on current practices and theories on operation of trickling filters, it was felt that a study of the effect of hydraulic loading should be given lowest priority of the four variables. Therefore, it was decided that during the initial investigation all runs would be made at a reasonable and conventional hydraulic loading of 25 to 30 m.g.a.d. The method of operation for the plant was based on adjusting the influent flow to the filters to apply a B.O.D. loading of the desired order of magnitude, and regulation of recirculation to produce a constant hydraulic loading. This reduced the number of variables under investigation to the three which were considered to be especially important—B.O.D. loading, recirculation ratio, and temperature.

Over the 180-day period in which data were obtained for determining design factors, it was necessary to alternate between single- and two-stage operation. This was required to establish the equivalence of performance of the two filters and to determine efficiencies with the two methods of operation over a range of variations in temperature and waste characteristics. With two-stage operation, of course, the

first filter provided additional single-stage data at high B.O.D. loadings.

Consequently, the data were collected over wide ranges of B.O.D. loadings, recirculation ratios, temperatures, and waste characteristics, with very little replication under any one set of conditions. Therefore, it was not possible to analyze the results by making plots of performance against any one variable with all of the other variables held constant. In this investigation time was not available to permit collection of the mass of additional data which would have been required for that type of analysis.

Actually, the usual procedure of replicating each set of conditions until the performance of a unit can be defined precisely by such simple procedures, is very inefficient from the standpoint of amount of experimentation required. Modern statistically designed experiments, as first proposed by Fisher (10), obtain much more information from a given amount of data. However, because of the lack of control over B.O.D. loadings, uncertainties as to inhibitory effects of certain individual waste compounds, and the necessity for day-to-day evaluation of results to obtain certain special information, this series of studies was not completely planned in advance in a nicely balanced experimental design. Rather, the changes in conditions were made at irregular intervals, based on daily evaluation of the data and engineering judgement of the supervisory personnel.

Fundamental Considerations

The statistical technique known as regression analysis is ideally suited to extracting a great amount of information from the type of data collected during this investigation. Regression analysis is the derivation, by the method of least squares, of an equation of sufficient power to describe the effects of variables on the performance of a system.

The three variables under consideration in this study were known from past history to have effects on the system. Since their effects were suspected to be related and non-linear, it was felt that an equation in the first degree, in which each variable could be defined independently of the others by a straight line, would be inadequate. Therefore, it was decided to fit a second degree polynomial to the data, since this type of equation usually will have sufficient power to describe such a system. The general equation for a second degree polynomial with three variables is as follows:

$$Y = b_0 + b_1X_1 + b_2X_2 + b_3X_3 + b_{11}X_1^2 + b_{22}X_2^2 + b_{33}X_3^2 + b_{12}X_1X_2 + b_{13}X_1X_3 + b_{23}X_2X_3 \quad \ldots\ldots (1)$$

in which

Y = Fraction of B.O.D. removed;

X_1 = B.O.D. loading;

X_2 = Temperature;

X_3 = Recirculation ratio; and

b_0, b_1, b_2, etc., are constants which must be determined by the method of least squares.

The method of least squares, using this equation, will fit some section of a conic (such as an ellipse or a parabola) to the data so that the sums of the squares of the deviations of the actual values from values given by the equation will be a minimum.

There are 10 constants to evaluate in a full second degree polynomial of three independent variables. Determination of these constants by the least squares method requires the simultaneous solution of 10 equations having 10 unknowns. However, it is possible that within a practical range for each of the variables, some of the factors in the equation may be so small that their elimination would have only

a negligible effect on the accuracy of the equation. Therefore, in some cases it may not be necessary to solve for all of the terms in the general equation. Each factor that is dropped means that one equation and unknown may be eliminated from the ten. Decreasing the number of equations in this fashion decreases the amount of work necessary in the over-all solution by a much greater proportion.

Fortunately, a procedure exists which permits calculation of the sum of squares from an equation having one or more terms of the general equation, and stepwise calculation of the reduction in this sum of squares resulting from addition of other terms. The general equation then may be simplified without affecting its accuracy, and the amount of calculation reduced, by eliminating terms which have insignificant effects. This procedure is known as an abbreviated Doolittle method, and is described in detail by Anderson and Bancroft (11).

Single-Stage Operation—Stepwise Solution

A preliminary analysis was made before all of the data were obtained for single-stage operation of the filters. Using the abbreviated Doolittle procedure, the sum of squares of the deviations from an equation in terms of the variables X_1, X_2, and X_3 was calculated. Then the procedure was used to determine how much the inclusion of the square and cross-product terms in the general equation would reduce the sum of squares. This method of checking the effect of additional terms is shown in Table I.

The terms included in the preliminary analysis are shown in Col. 1, Table I. The sum of the squares of deviations from an equation having terms in X_1, X_2, and X_3 is shown as 1.6598 in Col. 3. The mean square of deviations from the equation may be determined by dividing the sum of squares in Col. 3 by the appropriate degrees of freedom. The degrees of freedom for the mean squares under each set of conditions are equal to the number of observations (147 days) minus the number of constants in the fitted equation, and are listed in Col. 5. The mean squares of deviations from an equation containing X_1, X_2, and X_3 would be 0.01161, as shown in Col. 6.

The second line in Table I was computed to determine the effect of adding

TABLE I.—Investigation of Significance of Terms Considered for Addition to Basic Equation (Using Abbreviated Doolittle Procedure)

(1) Terms in Equation	(2) Terms to Be Added	(3) Sum of Squares of Deviations from Equation	(4) Reduction in Sum of Squares	(5) Degrees of Freedom	(6) Mean Squares	(7) Degrees of Freedom	(8) Reduction in Mean Squares	(9) Ratio: Col. 8 / Col. 6	(10) Does Term Add Significant Value?
b_0, b_1X_1, b_2X_2, b_3X_3	—	1.6598	—	143	0.01161	—	—	—	—
Same	$b_{11}X_1^2$	1.6510	0.0088	142	0.01163	1	0.0088	0.8	No
Same	$b_{22}X_2^2$	1.6594	0.0004	142	0.01169	1	0.0004	0.0	No
Same	$b_{33}X_3^2$	1.6384	0.0214	142	0.01154	1	0.0214	1.9	No
Same	$b_{12}X_1X_2$	1.6554	0.0044	142	0.01166	1	0.0044	0.4	No
Same	$b_{13}X_1X_3$	1.5915	0.0683	142	0.01121	1	0.0683	6.1	Yes
Same	$b_{23}X_2X_3$	1.5638	0.0960	142	0.01101	1	0.0960	8.7	Yes
b_0, b_1X_1, b_2X_2, b_3X_3, $b_{23}X_2X_3$	$b_{13}X_1X_3$	1.5423	0.0215*	141	0.01094	1	0.0215	2.0	No

* Sum of squares subtracted from sum immediately above, which contains X_1, X_2, X_3 and X_2X_3 terms.

a term in X_1^2 to the preliminary equation in X_1, X_2, and X_3. From Col. 3 it may be seen that the sum of squares of the deviations from this equation would be 1.6510, or 0.0088 less than the preliminary equation, as shown in Col. 4. With 142 degrees of freedom, the mean square of the deviations was found to be 0.01163.

The reductions in mean squares (Col. 8) are computed by dividing the reduction in sums of squares (Col. 4) by the degrees of freedom shown in Col. 7. The degrees of freedom for the reduction in mean squares (Col. 7) are equal to the number of terms added in Col. 2.

The ratio of the reduction of mean squares (Col. 8) to the mean squares (Col. 6) attending the addition of a term is a measure of the value of that term in the equation. There is a statistical technique, known as the F test, which can be used to determine the significance of these ratios. This test using one degree of freedom is not as critical as usually desired for determining whether factors should be included in the general equation. However, for equations which are used only to define areas of operation within the range of the variables studied, the technique as used will result in equations of sufficient accuracy. The reader is referred to a more detailed discussion of this procedure (11) for further information. It is sufficient for the purposes of this article to state that, for this solution, ratios greater than about 4 could be considered significant. It may be seen from Col. 9 that addition of the X_1^2 factor gave a ratio of about 0.8. Therefore, addition of this term would not have significant effect on the accuracy of the equation, and it need not be included.

This procedure is repeated in Table I for each of the remaining terms in the general equation. It may be seen that none of the added terms proved significant except for X_1X_3 and X_2X_3. With either of these two terms the reduction in mean squares was sufficiently large to show benefit by their inclusion in the equation. Because X_2X_3 had the greater effect, the next step was to determine the significance of adding X_1X_3 to an equation containing X_1, X_2, X_3 and X_2X_3. This computation is shown in the last line of Table I. This did not prove significant; therefore, the X_1X_3 term could be dropped, and only X_1, X_2, X_3, and X_2X_3 are required to be included in the equation.

The least squares solution in terms of these factors resulted in

$$Y = 0.6398 - 0.003117X_1 - 0.001865X_2 - 0.2226X_3 + 0.003861\,X_2X_3 \quad \ldots\ldots\ldots\ldots (2)$$

in which

Y = Fraction of B.O.D. removed;

X_1 = B.O.D. loading, in 100 lb. per acre-foot per day;

X_2 = Temperature, ° F.; and

X_3 = Recirculation ratio.

It is to be expected that if Eq. 2 is solved for the fraction of B.O.D. removed under the conditions of loading, temperature, and recirculation ratio prevailing during each of the 147 days in the test period, the calculated values will deviate from the actual B.O.D. removals observed in the field. These differences are called "residuals." The residuals are a measure of the inherent variability of the system, which is caused by such factors as effluent variability, analytical error, and errors in operation of the unit; plus the error of the approximation of the equation to the true functional relationships. The standard deviation of the residuals is the square root of the mean squares. For Eq. 2 the standard deviation is $(0.01101)^{\frac{1}{2}}$, or about 0.1 in terms of fraction of B.O.D. removed. This means that about 65 per cent of daily values predicted by using the equation should be within a range of 10 per cent B.O.D. removal from the observed value, and about 95 per cent should be within a 20 per cent range.

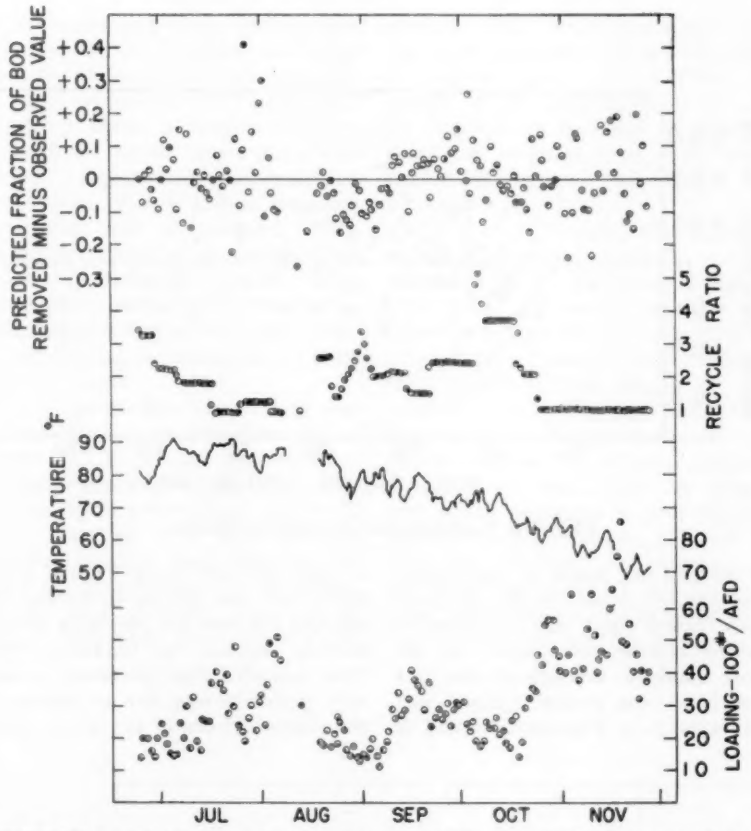

FIGURE 1.—Distribution of residuals and variables for single-stage operation; preliminary analysis.

Residuals were actually computed for each day of the test period by using electronic computers to solve Eq. 2 for the combination of variables recorded in the field. These residuals are plotted in chronological order in Figure 1.

The distribution of residuals is quite important. If there are no unknown significant factors that vary in a systematic way, the residuals should be randomly distributed. During the latter part of August and the first part of September the residuals were almost all negative; during the latter part of September they were positive. This indicates that some unmeasured variable has shifted during the period, or that the equation used was a poor approximation to the true relationship. Residuals obtained during the remainder of the test period appear to be random in nature.

In Figure 1, the B.O.D. loading, recirculation ratio, and temperature have been plotted chronologically. It may be seen that recirculation ratio and temperature did not exhibit trends similar to the trend in residuals between August 15 and September 30. However, the loading did have a similar trend during this period. Therefore, it appeared that the grouping of the residuals was due to a change in char-

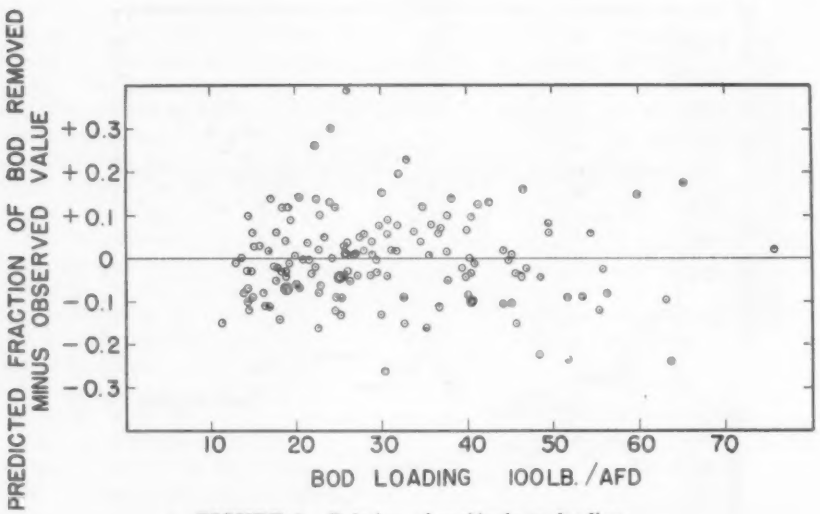

FIGURE 2.—Relation of residuals to loading.

acteristics of the waste, or inadequacy of the loading terms in the equation.

As a further check into the cause for grouping during this period the residuals obtained throughout the test period have been plotted against each main variable in Figures 2, 3 and 4. It may be seen from Figure 2 that there does not appear to be any correlation between the residuals and the loading applied to trickling filters. This indicated that the trend in residuals probably was due to changes in the characteristics of the waste, rather

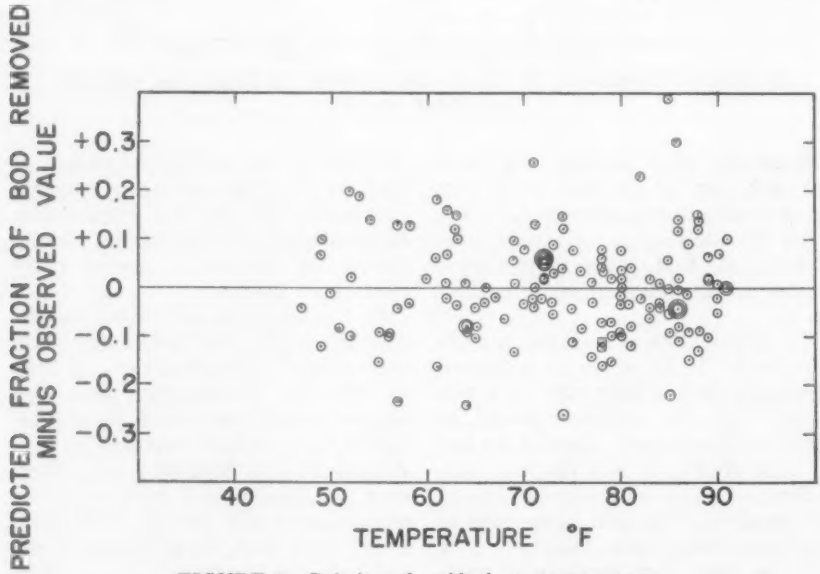

FIGURE 3.—Relation of residuals to temperature.

than to inadequacy of the loading factors in Eq. 2. Examination of Figure 3 leads to the conclusion that the residuals were not related to temperature.

Figure 4 shows a definite relationship between recirculation ratio and variance of the residuals, inasmuch as the dispersion of residuals decreases as recirculation ratio is increased. This does not appear to be an unreasonable type of relationship, because with greater recirculation ratios the damping of variables in the feed to the filter, through dilution by recirculating flow, would be greater.

A large proportion of the data was obtained at low recirculation ratios (Figure 4). In a least squares solution, observations having a large variance have more weight than those with smaller variance. It was decided therefore, in the final analysis, to weight the observations by the reciprocal of their residual variances in order to give each observation equal weight. This would make the equation more accurate over the full range of recycle ratio. For a fuller discussion of the procedures which must be followed in deriving an equation based on weighted least squares, the reader is referred to Bennet and Franklin (12).

The true relationship between recirculation ratio and residual variance was not known. Therefore, it was approximated by calculating the variances of groups of residuals from the preliminary equation from observations within certain ranges of recirculation ratio. The logarithm of the reciprocal of these variances was plotted against the average recirculation ratio in each range. A straight line which appeared to best fit these points was then drawn (Figure 5). This line was used to determine the weighting factor which should be applied to the observations in deriving the final equation by weighed least squares.

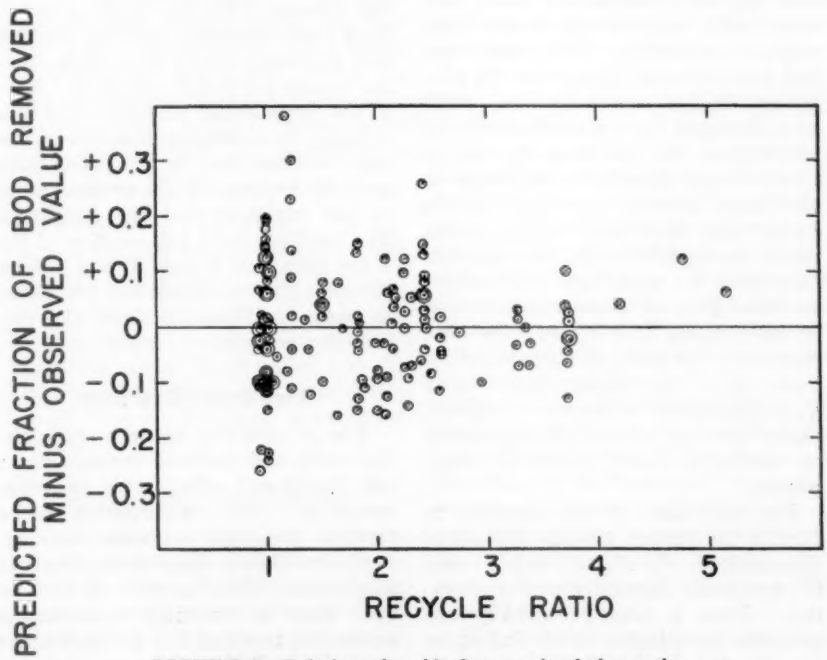

FIGURE 4.—Relation of residuals to recirculation ratio.

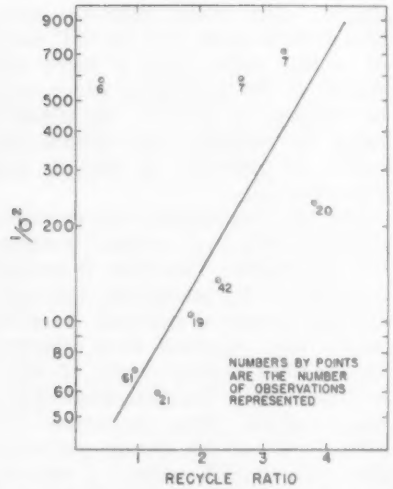

FIGURE 5.—Relation between variance of residuals and recycle ratio.

Single-Stage Operation—Full Solution

Weighting the observations in a second degree polynomial of three variables adds considerably to the least squares calculation. Also, more data had been collected by the time the foregoing solution was completed, which also increased the required amount of calculation. In addition, the ranges of the three variables were larger in the final solution, resulting in the probability that more of the terms would be significant in the equation, increasing the work load still further. In view of all of these considerations, it was decided that it would be more economical to have the computations made by a computing agency with a medium-sized electronic computer, rather than by using desk calculators or available small electronic computers.

The only data it was necessary to furnish the agency was the full set of observations, X_1, X_2, X_3 and Y, and the weighting factor for each observation. Since a program already was available for solution of the full equation by the computers, it was more economical to obtain the constants for all terms in the general equation than to follow the stepwise procedure outlined previously for deriving an abbreviated equation.

The information obtained from the computers consisted of the constants for each term in the general equation, resulting in

$$Y = -0.08549 - 0.002413X_1 + 0.01058X_2 + 0.06555X_3 - 0.00001709X_1^2 - 0.00007789X_2^2 - 0.02120X_3^2 + 0.00006954X_1X_2 - 0.002327X_1X_3 + 0.002127X_2X_3 \quad (3)$$

Examination of Eq. 3 indicated that all but the X_1^2 term had significant effect on the computed B.O.D. removal percentage within the range over which the variables had been studied. It is probable that if the stepwise solution had been followed, several of the terms might have been dropped from the final expression. However, the remaining constants in the equation would have been somewhat different, and the two equations would have given similar results for B.O.D. removals. More of the terms would probably have been retained in a stepwise solution on the final analysis than in the preliminary analysis because of the greater range of the variables and the weighting. The residuals from full solution of Eq. 1 are shown in Figure 6, and exhibit the same general trends and dispersion as those in Figure 1 from the preliminary equation.

Two-Stage Operation

The relationship between recirculation ratio and residual variance has a less significant effect with two-stage operation. The recirculation ratios used in two-stage operation were effectively higher than those used in single-stage, since a ratio of 1:1 on each filter in two-stage operation is equivalent to about 3:1 in single-stage operation. Because the relation be-

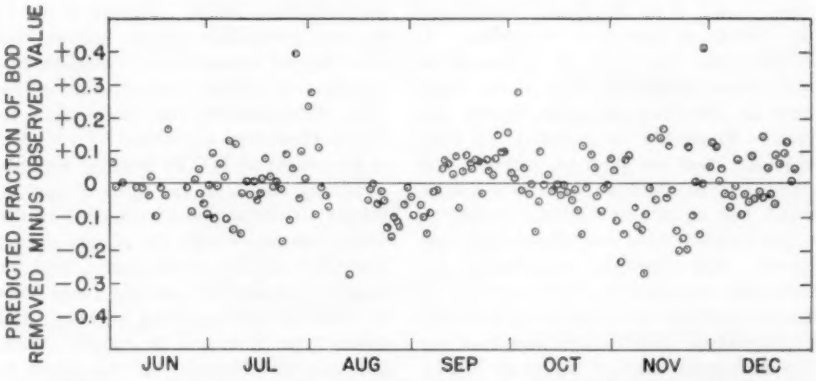

FIGURE 6.—Distribution of residuals for single-stage operations; final analysis.

tween variance of residuals and recirculation ratio is logarithmic, the higher effective recycles with two-stage operation would give a lower range in weighting factors than single-stage. Also, the over-all variance of the residuals would be less.

It was decided, therefore, not to weight the observations in the two-stage analysis. Without weighting, and with fewer observations, the amount of calculation was small enough so that the stepwise procedure and a desk calculator could be used for the solution. This resulted in the derivation of

$$Y = -0.5448 - 0.004405X_1 + 0.03130X_2 + 0.1858X_3 - 0.0001996X_2^2 - 0.03465X_3^2 \ldots (4)$$

The residuals from Eq. 4 were plotted chronologically and found to be distributed in random fashion. Therefore, it can be concluded that the abbreviated solution was satisfactory for deriving the equation for two-stage operation.

Engineering Interpretation

The equations which have been developed statistically indicate that—as expected from past work on trickling filters—loading, recirculation, and temperature have non-linear effects on performance. In addition the cross-product terms indicate that these variables are not independent in their effects. This possibility has not usually been considered in the work of past investigators.

In statistical terms, the interdependence of these variables is called interaction. The statistical significance of the X_2X_3 term, for example, indicates that there is a temperature-recycle interaction. This means that the effect of changing the recirculation ratio from one level to another varies with temperature.

The purpose of this investigation was to determine the design factors for trickling filters to treat this particular waste. The constants in the equations which have been developed are valid only for this waste. However, the form of the equations which indicate the nature of the effects of the variables should be generally valid for trickling filters.

The absence of cross-product terms from the two-stage equation does not mean that there is no interaction in the effect of the variables. The range of the variables in two-stage operation was smaller than for single-stage and the interaction effects may not have been large enough to detect over the smaller range.

The two final equations have been expressed in graphical form in Fig-

ures 7 and 8 to facilitate visualizing the effects of the three variables. It is felt that this type of presentation is of more practical value to the engineer in selecting optimum design criteria. It should be pointed out that caution must be used in interpreting these curves, because it is possible to solve the equations beyond limits of experimental data on which they are based. For example, solution of the two-stage equation for B.O.D. removals which would be obtained with loadings greater than 1,000 lb. per acre-foot per day and recirculation ratios of 2:1 or 3:1 would not be valid, since the plant was not operated under these conditions at any time. In similar fashion, solution of either equation for recirculation ratios above 4:1 would not be proper, as higher recirculation ratios were not investigated during this period of experimentation.

From Figures 7 and 8 it is evident that temperature had a radical effect on B.O.D. removal at all loadings and recirculation ratios. Figure 8 shows, by increased slope of the curves, that the effect of temperature was more pronounced at higher recirculation ratios. This demonstrates the interaction between these two variables.

The effect of B.O.D. loading was surprisingly small, in the light of current theory on the action of trickling filters, when compared with the effects of temperature and recirculation. For example, a change in loading from 2,000 to 1,000 lb. per acre-foot per day, with either type of operation, would change the over-all efficiency of the plant by less than 5 per cent.

The effect of recirculation was pronounced with both single- and two-stage operation of the units, although it was more significant with the former. This appears reasonable, because a 1:1 recirculation ratio represents four theoretical passes through filter beds operated in series, and only two passes through a single filter. Therefore, it could be expected that increased recir-

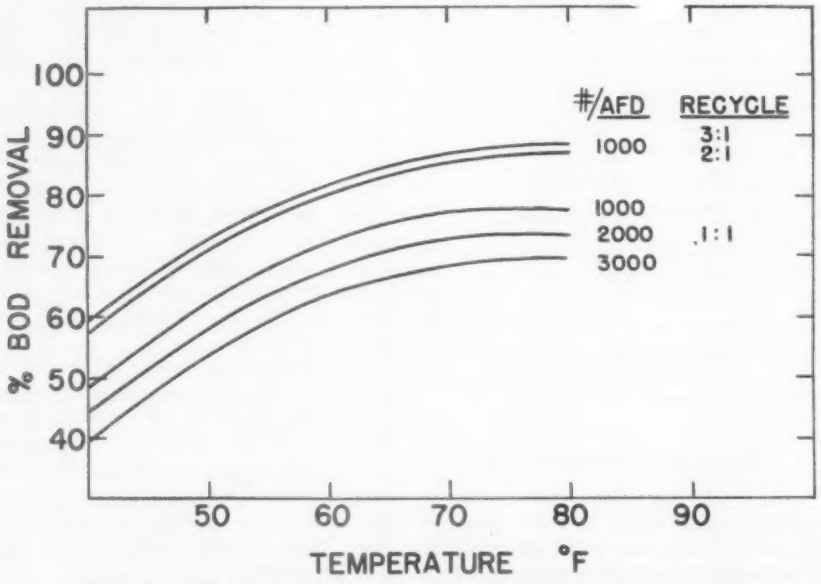

FIGURE 7.—Performance of two trickling filters operated in series.

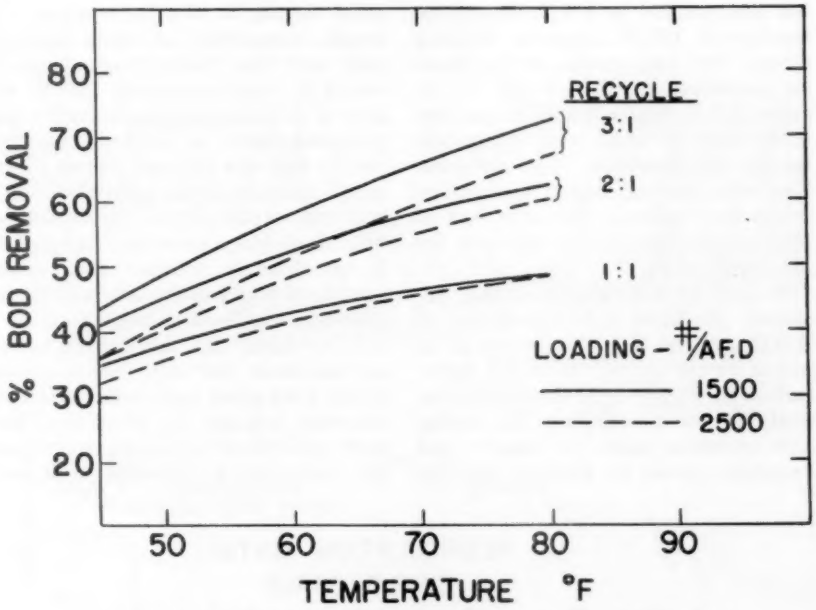

FIGURE 8.—Performance of single-stage trickling filters.

culation would show more improvement in a single-stage plant. Limited data on higher recirculation ratios appear to indicate that with series operation little would be gained in treatment of this particular waste by providing recirculation flows greater than 2:1.

The relative effects of B.O.D. loading and recirculation ratio, as found from this study, are similar to those noted by Rankin (13) in an article analyzing operating data from several trickling filter plants. In that study it was observed that: "Performance of the plants cited appears to be dependent primarily upon one factor, the ratio of recirculation. Dosing rate, loading of the filter or depth of filter have no significant effect within the range of values covered by the data."

Therefore, the design of a full-scale trickling filter plant for this waste would be largely based on recirculation ratio. The size of the filters could be governed by hydraulic loading, inasmuch as permissible hydraulic loading would limit the extent to which recirculation could be applied. Recent work (14) appears to indicate that hydraulic loadings could be increased substantially above the conventional 30-m.g.a.d. loading without impairing filter performance significantly. Hence, it would be reasonable to continue pilot-plant work at higher B.O.D. loadings, with greater recirculation ratios and substantially higher hydraulic loadings. The use of filters less than 6 ft. in depth should be considered, because area rather than volume might govern filter size.

Using the two equations which have been developed, it is possible to make an economic comparison of single- and two-stage installations for treatment of this particular waste. The basis for such an economic study is presented in Figure 9, in which the percentage of B.O.D. removal by each type of plant

has been plotted as a function of the number of 165-ft. diameter trickling filters. For preparation of this figure an operating temperature of 77° F. and a B.O.D. load of 40,000 lb. per day in 30 m.g.d. of waste were assumed in solving the equations. The recirculation ratio was calculated in each instance to produce a hydraulic load of 30 m.g.a.d., which is in line with the pilot-plant work.

It may be seen that two-stage operation produced a better degree of B.O.D. removal than single-stage at all points on the curve. With the information in Figure 9, it should be relatively simple to compare the capital and operating costs for single- and two-stage plants to produce any desired degree of B.O.D. removal. A rough comparison of costs indicate that with this waste, series operation would be more economical for the degree of B.O.D. removal required in the proposed plant. A further consideration is that the ultimate degree of removal attained during pilot-plant work was higher with series operation than with single-stage operation, although it is questionable whether this would have been true had the single-stage recirculation ratios been higher.

It is evident that this type of analysis facilitates not only interpretation of the pilot-plant data with maximum accuracy, but also the selection of the most economical operating conditions for designing a full-scale treatment

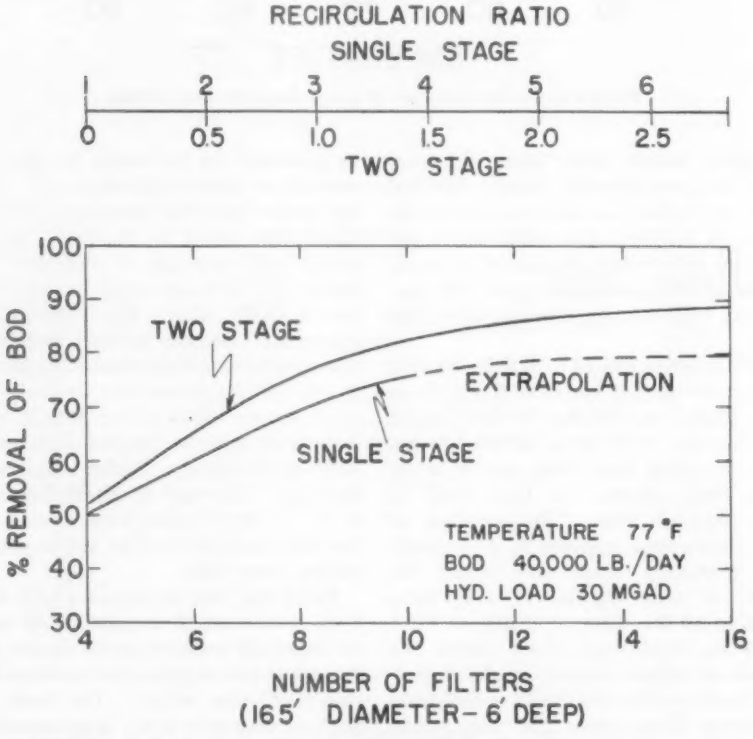

FIGURE 9.—Performance of single- and two-stage filter plants; filters 165 ft. in diameter and 6 ft. deep.

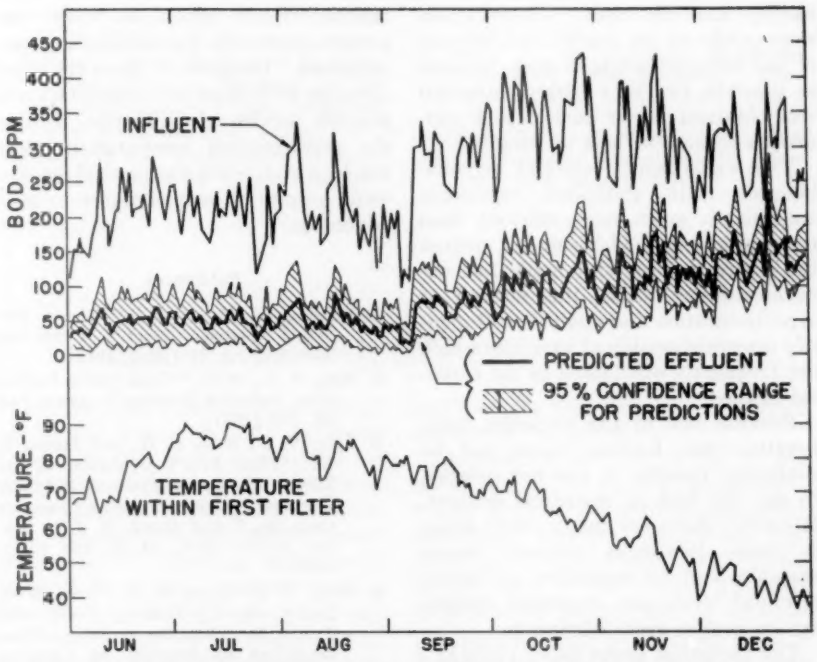

FIGURE 10.—Predicted effluent from a plant with eight 165-ft. diameter filters and two-stage operation.

plant. As a final check on the performance which could be expected from the full-scale treatment plant, it is possible to solve the appropriate equation to show B.O.D. removals which would have been produced on a day-to-day basis over any period for which data are available.

This has been done as an illustrative example, assuming that the plant would consist of eight 165-ft. diameter filters arranged in two equal groups for series operation. Using electronic computers, the two-stage equation was solved for the conditions of temperature, B.O.D. loading, and recirculation ratios which would have been encountered during each day from June to December, 1955. The influent and computed effluent B.O.D. values during this period are shown in Figure 10, along with the approximate 95 per cent confidence limits for the predicted effluent B.O.D. Examination of the curves makes it possible to determine whether or not there would be any periods in which the effluent B.O.D. might exceed a specified limit. The influence which temperature would have on the plant performance is shown by the sharp increase of effluent B.O.D. during the months of November and December.

Summary

Statistical procedures have been described which were used for analyzing data from a trickling filter pilot plant to obtain design information. An unusual feature of this pilot-plant investigation was that the classical method of experimentation, of holding all variables but one at a constant level and varying that one over the desired

range, was not used. Observations were made at as many combinations of the different levels of each variable as possible, but very little replication was obtained under each set of conditions because of lack of time.

This experimental method, in combination with statistical regression analysis, is much more efficient than the classical method because it defines the entire system with much less experimentation. Also, this method of experimentation and analysis will identify interrelationship of variables which are frequently overlooked in the classical method.

Because two of the variables, temperature and loading, could not be controlled exactly, it was not possible to use the best of statistical designs. However, there are many other areas in waste treatment research where variables can be controlled at predetermined levels and statistical designs can be used to great advantage.

The statistical books listed (10) (11) (12) (15) cover the mathematical techniques of analysis used in this example and the subject of experimental design. However, they do require some facility in elementary mathematics and unless the experimenter is so inclined, and is willing to spend some time learning the techniques, he is advised to consult a statistician on the design and analysis of his experiments. Most large companies employ statisticians and there are many private statistical consultants.

Statistical calculations of the type described in this paper can be very time consuming. There were no computations in this analysis which could not be done on a desk calculator. However, in many cases, either because of the urgency or economics of the situation, it is advantageous to use an electronic computer. Most large companies have in their accounting departments electronic computers which also can be used for engineering calculations. Some companies have computers exclusively for engineering computations. In addition, there are many agencies with electronic computers who provide service of this type, so that the mathematical computations need not be a restrictive factor to those who could employ these techniques to good advantage.

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CERTIFICATION DEADLINE DATE EXTENDED

The American Sanitary Engineering Intersociety Board recently extended the deadline date to October 1, 1957 for receipt of applications to be considered for certification without examination.

The extension was adopted to permit members of the American Institute of Chemical Engineers, recently voted a sponsor of the Board, an opportunity to take advantage of the possibility of certification without examination. The American Industrial Hygiene Association has also been invited to become a sponsor of the Board.

Certification is given in one of five specialties of Sanitary Engineering—Public Health, Air Pollution Control, Industrial Hygiene, Radiation Hygiene and Hazard Control, and Water Supply and Waste Water Disposal. Requests for information or application forms should be addressed to the Board at 33 West 39th St., New York 18, N. Y.

CORRECTION

In the paper, "Some Experiments on the Toxicity of Complex Cyanides to Fish," by Peter Doudoroff (THIS JOURNAL, **28**, 8, 1020; Aug., 1956), the following corrections should be made:

1. In the twelfth line of the first column on page 1021, the formula, "$Ni(CN_4)^{=}$" should read "$Ni(CN)_4^{=}$."
2. In the fourteenth line of the first column of text on page 1025, the formula, "$Zn(CN_4)^{=}$" should read "$Zn(CN)_4^{=}$."
3. In the twelfth line of the first column of text on page 1026, the formula, "$Cd(CN_4)^{=}$" should read "$Cd(CN)_4^{=}$."

(Elsewhere in the paper the ionic formulas are correctly written.)

4. In the eighth line of the first column of text on page 1030, the words "than at pH 6.5" should read "as at pH 6.5."

THE OPERATOR'S CORNER

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SLUDGE DEWATERING AT UNION CITY, TENNESSEE *

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During the last few years considerable attention has been focused on the disposal of sewage sludge, particularly on the developments for dewatering sludge. Among these developments has been the coilfilter-type vacuum filter.‡ The coilfilter now in use at the Union City, Tenn., sewage treatment plant was the first such unit installed in Tennessee and one of the first in the South. Widespread interest has been manifested in the operating experiences and costs for this type of sludge dewatering.

Plant Layout

The present population of Union City is approximately 8,000, and the sewage treatment plant (Figure 1) was designed for a future population of 11,000 persons. It was estimated that the Reelfoot Packing Company, the principal contributor of industrial wastes, would deliver a flow of 0.23 m.g.d. to the plant, and the average flow of municipal sewage would be 1.0 m.g.d. Plant units were designed on the basis of an average flow of 1.23 m.g.d. It was estimated that the total B.O.D. load on the treatment plant would be 2,665 lb. per day. This was based on the agreement that the packing company would reduce the strength of its waste so the B.O.D. would not exceed 500 p.p.m. The Reelfoot Packing Company waste had not been diverted to the sewage treatment plant during the operating period described here.

The raw sewage entering the plant passes through a comminutor and a grit removal unit which removes and washes the grit. Sewage is then pumped to the primary tanks where it is measured. The two rectangular primary tanks are 16 ft. by 43 ft. each and have a sidewater depth of 9 ft. The detention time provides 1.36 hr. for average flow in an 18-hr. day. The primary effluent can be directed to either trickling filter or aeration tanks.

In normal use the sewage flows to the trickling filter, which is used as a roughing filter. The 50-ft. diameter filter is 4.5 ft. deep and a B.O.D. reduction of approximately 35 per cent is obtained at a B.O.D. load of 8,712 lb. per acre per day. The filter eliminates shock loads to the aeration tanks. Sewage from the filter returns to a wet well where it is pumped to the aeration tanks. The two aeration tanks are

* Presented at the 1956 Annual Meeting, Kentucky-Tennessee Industrial Wastes and Sewage Works Assn.; Chattanooga, Tenn.; Sept. 17–19, 1956.

† Present Address: Russell & Axon, Consulting Engineers, Daytona Beach, Fla.

‡ Manufactured by Komline-Sanderson Engineering Corp., Peapack, N. J.

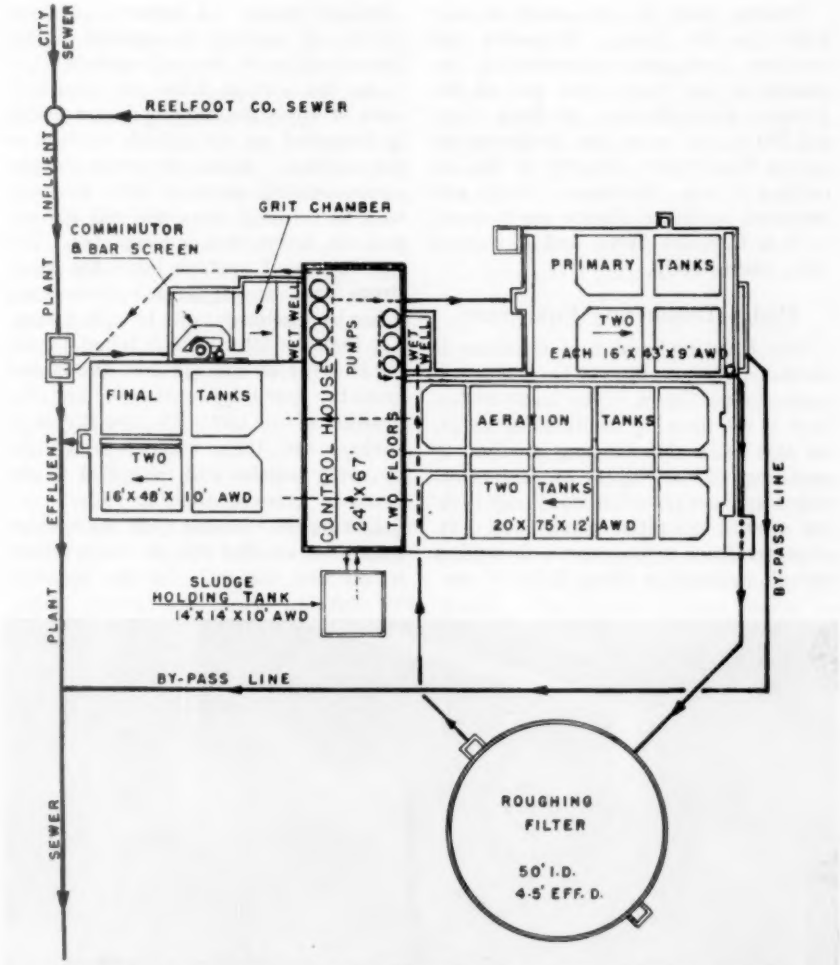


FIGURE 1.—Flow diagram of the Union City, Tenn., sewage treatment plant.

each 20 ft. by 75 ft. and have a side-water depth of 12 ft. They provide an aeration time of 5 hr. at average flow. Air is supplied at an average rate of 1,000 cu. ft. per pound of applied B.O.D. Final clarification takes place in two rectangular settling basins where a retention time of 2 hr. is provided.

Waste activated sludge and primary tank sludge are pumped to a hopper-bottom sludge-holding tank which provides approximately one day of sludge-holding time. Sludge is pumped from the holding tank to the coilfilter when the operator begins filtering.

All pumps, sewage piping, blowers, water seals and auxilliary equipment are located on the lower floor of the plant control house. The upper floor is equipped with a large modern laboratory, a workshop, employee lockers, metering facilities, chemical storage room, and the sludge filter.

Sewage may be by-passed at any point in the plant. Excessive wet weather flows are automatically by-passed at the plant inlet and at the primary tank effluent. At flood stage, a 2,250 g.p.m. pump can discharge the excess flood water directly to the receiving stream. By-passed sewage and returned activated sludge are metered with a Parshall flume and a venturi tube, respectively.

Sludge Dewatering Equipment

The Komline-Sanderson Coilfilter is similar in some respects to other vacuum sludge filters. The basic difference is the filtering media (Figure 2). In this case, the filtering medium is made up of two layers of alloy steel coiled springs placed in corduroy fashion around the filter drum. The 7-ft. diameter filter drum rotates through a trough containing about 2 ft. of conditioned sludge. A vacuum of about 15 in. of mercury is applied to the inner surface of the coil springs.

As the springs leave the liquid, a cake of approximately ½ in. of sludge is deposited on the outside surface of the springs. After the drum rotates approximately another 180° the vacuum is released from the coil springs and the dewatering is completed. The two layers of springs leave the large drum and are separated from each other by discharge rolls in such a manner that the filter cake is lifted off the lower layer of springs and discharged from the upper layer with the aid of a positioned tine bar. The two layers of springs are then washed separately by spray nozzles and reapplied to the drum by grooved aligning rolls.

During the washing cycle the springs pass over another set of small rollers which flex the coils in the opposite

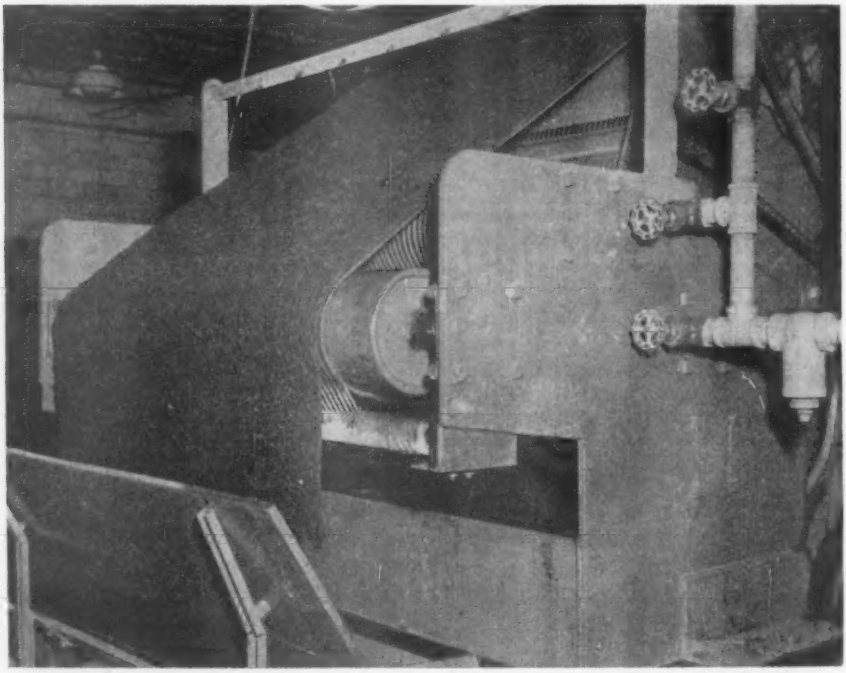


FIGURE 2.—Coilfilter in operation. Note the continuously-wound spring coils that constitute the filter media.

direction to that of normal rotation. This assures complete washing on both sides of the springs. Vacuum filtrate and coilspring washwater are returned to the raw sewage wet well.

One of the accessories to the coilfilter is a 75-gal. sludge conditioning tank in which the necessary chemicals are added to the sludge to be filtered. Sludge is pumped to the tank by a diaphragm-type sludge pump furnished with the coilfilter. Motors for the coilfilter include a 10-h.p. vacuum filtrate pump drive, a 1½-h.p. agitator drive, a 1-h.p. drum drive, a 1-h.p. filtrate pump drive, a 3-h.p. sludge pump drive, and a ⅓-h.p. mixing motor. Accessory units also include a ferric chloride pump and a lime feed machine.

During the filtering process sludge is pumped directly from the sludge-holding tank to the sludge-conditioning tank. Lime and ferric chloride are added in the conditioning tank and mixed with a rocker-type mixing device. Sludge flows by gravity from this tank to the trough through which the filter coils rotate. The trough is equipped with a slow-motion agitator to maintain a constant thickness of sludge. The variation in rate of sludge removed by the vacuum process sometimes causes the diaphragm sludge pump to overfill the sludge trough; as a result, the pump must be stopped manually. It has been observed that the sludge filter would require less constant attention if some means could be provided for stopping and starting the diaphragm pump automatically with the sludge level in the trough.

Operational Features

A small amount of waste activated sludge is pumped to the sludge-holding tank at all times. Raw sludge from the primary tanks is pumped to the sludge-holding tank twice daily. Lime is added to the raw sludge in small quantities as it is being pumped, to assist in conditioning the sludge.

In the original installation, the sludge-holding tank was provided with an overflow for automatic supernatant return. It was evidently assumed that the sludge would settle and concentrate, but this was not the case. The sludge stratified on standing, causing a heavy blanket of sludge to float on the surface with layers of water below. Consequently, extremely watery sludge was sometimes pumped to the coilfilter. The watery sludge was difficult to filter and the filtration time often was excessive. It became apparent that some method must be devised for concentrating the sludge, if filter operation was to be economical.

The original installation had an additional drawback. The overflow from the holding tank was a concentrated and sometimes septic sludge. This sludge was returned to the raw sewage wet well where it passed through the plant. The septic sludge floated on the surface of the primary tank and caused odors. It also seemed to break down the activated sludge floc in the aeration tanks.

In an effort to eliminate this problem the plant superintendent installed three 3-in. drawoff lines in the holding tank at different levels. The lines and valves were so arranged that the liquid being drawn could be observed. This arrangement made it possible to concentrate the sludge effectively by drawing supernatant from whatever level it had sought on any particular day, being careful not to allow any overflow from the top.

Later, some difficulty was noted in pumping sludge to the filter as a result of the solidification of the stratified layers in the holding tank, particularly the floating top layers. This difficulty was eliminated by the installation of a 1-in. air line to the bottom of the holding tank. The small amount of air bubbled through the sludge was effective in breaking up sludge layers and providing a uniform sludge for filtration.

Experience at the Union City plant has shown that the moisture content of the sludge is important. Where excess liquid is handled with the sludge, the filter cake is thinner, more lime and ferric chloride are needed for coagulation, and filtering time is much longer.

Sludge Disposal

The filtered sludge from the coilfilter drops onto a conveyor and is carried outside the building where it is deposited in an elevated metal sludge hopper to provide for truck loading. The filtered sludge has a moisture content of approximately 65 per cent and the consistency of half-dried mud; however, due to its fibrous nature, it does not pack excessively. The conical bottom of the sludge hopper slopes at 60° from the horizontal. Apparently this slope is not sufficient, because some difficulties have been experienced due to solidification of sludge around the gate in the bottom of the hopper.

The sludge discharged from the coilfilter is too moist to be distributed efficiently by a conventional manure spreader; although it can be done. When the sludge is allowed to dry for a week or two, it can be spread very effectively.

In the first months of operation a major portion of the dewatered sludge was hauled to a nearby farm. In more recent months local farmers have been taking most of the sludge. An inspection of the farm indicated that the sludge was already proving of benefit to the land.

The only difficulty encountered in disposing of sludge on farm land is the problem of distributing the sludge over the land in winter months when the farm roads are inaccessible. In the past, some of the sludge has been stockpiled at the farms and distributed at a later date. This requires handling the sludge twice, but has worked satisfactorily.

If the time should come that farmers do not want the sludge, the city now has areas nearby that could be used for landfill. Small amounts of the sludge have been used successfully in filling areas around the sewage treatment plant. The sludge dries rather rapidly and has little or no odor. It softens when rained upon but apparently does not return to its original state. The sludge seems quite stable and begins to attain a fibrous texture with aging. After about six months, it gradually disintegrates to the consistency of decayed organic matter.

Cost of Operation

The Union City sewage treatment plant began operation in July, 1955, although accurate records for the coilfilter were not kept until September, 1955. The records for the 12-month period, September, 1955 to August, 1956, are shown in Tables I and II. The data were compiled for each month so that the values shown are either the average or the total for the month.

The daily sewage flow was recorded from the raw sewage meter. The settleable solids, total solids, and sludge solids content were determined according to standard laboratory procedures. Chemicals used in sludge conditioning were weighed daily before batching. The amount of sludge filtered per day was measured by the use of a counter mounted on the previously calibrated diaphragm pump.

The cost of chemicals used was computed from the actual invoices of materials delivered. The cost of electricity was determined with the aid of the local electric company and was based on the size and efficiency of the motors used with the unit, including those used with the chemical feed pumps and the conveyor.

The labor cost was computed on the basis of the number of hours of filtering time. One-half of the operator's time was allocated to the operation of the coilfilter. Actually, the operator would have been required anyway for the proper operation of the plant. It

TABLE I.—Operating Data, Union City, Tenn., 1955–56

Date	Flow (m.g.d.)	Raw Sewage		Sludge Filtered (gal./mo.)	Sludge Solids, Dry (lb./mo.)	Sludge[1] (tons/mo.)	Sludge Conditioning Chemicals			
		Settleable Solids (%)	Total Solids (p.p.m.)				Ferric Chloride[2]		Lime[3]	
							(lb.)	(%)[4]	(lb.)	(%)[4]
(1955)										
Sept.	0.57	0.57	795	93,704	19,194	32.00	1,185	3.70	12,669	24.62
Oct.[5]	0.49	0.75	647	42,458	18,879	31.46	1,190	3.78	11,706	23.13
Nov.	0.54	1.10	654	101,200	43,642	72.74	1,645	2.26	9,660	8.26
Dec.	0.61	1.05	636	140,400	50,666	84.44	1,853	2.19	18,305	13.48
(1956)										
Jan.	0.74	0.84	603	126,400	44,791	74.65	2,888	3.87	17,650	14.70
Feb.	1.09	0.40	535	88,736	56,143	93.57	2,368	2.53	11,097	7.37
Mar.	0.86	0.83	—	82,171	42,932	71.55	2,650	3.70	9,451	8.21
Apr.[6]	1.03	0.70	686	88,280	32,395	53.99	1,751 841[7]	5.85	8,304	9.56
May	0.78	0.79	656	112,947	48,302	80.50	2,373	4.91	9,345	7.22
June	0.64	1.04	—	109,833	39,478	65.80	1,626	4.12	6,206	5.86
July	0.67	0.96	411	102,801	32,883	54.80	1,367	4.16	5,435	6.16
Aug.	0.65	1.02	667	108,339	32,484	54.13	1,397	4.30	5,440	6.20

[1] 70 per cent moisture.
[2] 60 per cent grade.
[3] 37.3 per cent CaO.
[4] Dry basis.
[5] Supernatant drawoff lines installed.
[6] Air line for mixing installed.
[7] Anhydrous $FeCl_3$, 98 to 100 per cent strength; used in succeeding months.

was observed that approximately one-half of his time was spent in checking the operation of the coilfilter.

Table I shows that the sludge production in September and October, 1955 was much less than for succeeding months. This was due undoubtedly to the fact that a portion of the sludge was returning to the plant through the overflow line from the sludge holding tank, and was eventually being discharged to the stream in the form of floating or suspended solids. The supernatant drawoff lines, installed in October, 1955, eliminated the problem.

It is apparent that the lime dosage was excessive in the first months of operation. The operators report that dosages of approximately 6 per cent now being used are equally as effective as the much higher dosages noted for the first five months of operation. The filter manufacturer claims that the cost of lime can be decreased even more by using a 74 per cent grade of lime. It has become evident that overdosage of chemicals can be even more costly than underdosage. Overdosage not only increases the cost of chemicals but increases the operation time. A ferric chloride dosage of about 4 per cent seems most effective in this plant.

In Table II it is noted that the cost of dewatering sludge varied from $43.57 per dry ton in September, 1955 to $17.84 per ton in June, 1956. The total cost for the year was $5,597.78 and averaged $24.24 per ton of dry solids. The fact that these costs are somewhat higher than those reported in other similar plants may be attributed possibly to several factors. It must be remembered that the data are for the first year of operation. The filter was new and the operators were inexperienced. They experimented considerably, and admittedly wasted time and chemicals occasionally in an effort to prove a theory. The cost of

TABLE II.—Sludge Dewatering Costs

Date	Ferric Chloride Cost[1] ($)	Lime Cost[2] ($)	Electric Power Cost[3] ($)	Labor Cost[4] ($)	Operation (hr.)	Total Cost ($)	Unit Cost ($)	
							Per Ton Dry Solids	Per Ton 30% Sludge
(1955)								
Sept.	130.94	164.70	23.53	99.06	181	418.23	43.57	13.07
Oct.	131.50	152.18	20.28	85.80	156	389.76	41.29	12.39
Nov.	181.77	125.58	26.52	112.20	204	446.07	20.44	6.13
Dec.	204.76	237.97	35.36	149.60	272	627.69	24.78	7.43
(1956)								
Jan.	319.12	229.45	28.08	118.80	216	695.45	31.05	9.31
Feb.	261.66	144.26	23.01	97.35	177	526.28	18.75	5.62
Mar.	292.83	122.86	22.88	96.80	176	535.37	24.94	7.48
Apr.	286.42	107.95	18.98	80.30	146	493.65	30.47	9.14
May	262.22	121.49	21.19	89.65	163	494.55	20.48	6.14
June	179.67	80.68	17.55	74.25	135	352.15	17.84	5.35
July	150.37	70.65	17.61	73.70	135	312.33	18.99	5.69
Aug.	154.37	70.72	15.53	65.73	119	306.35	18.86	5.65

[1] $FeCl_3$ at $0.1105 per lb.
[2] CaO at $0.013 per lb.
[3] Electricity at $0.13 per hr.
[4] Labor at $1.10 per hr.

chemicals has been considerably above average. For instance, ferric chloride has cost as much as $11.00 per hundred pounds, as compared with $4 to $8 in other locations. The holding tank troubles previously discussed added to the filtering time. It is apparent that economies resulting from mass-production techniques would not be applicable to the Union City plant, because of its small size. In addition, there were the problems and expenses which are inherent to the breaking-in of a new sewage treatment plant and should be less later on. It is believed that with proper operation, the cost of sludge dewatering at Union City subsequently could be reduced considerably.

Initial Construction Costs and Savings

The consulting engineers had estimated that the use of the coilfilter unit in place of a digester and sludge beds would reduce the initial construction cost of the sewage treatment plant by approximately $45,000. Alternate plans were drawn to permit a choice of the type of sludge handling units desired, after the opening of bids. The base bid included a conventional heated digester and sludge drying beds. The alternate bid omitted the digester and sludge beds, and included the coilfilter, the holding tank, and additional control house space. The results of the bids are given in Table III.

The actual net saving to the city was the difference between the low base bid and the low alternate bid, or $48,500. The dewatered-sludge hopper was added to the original bid at a later date. The cost of the hopper was $2,430.00. When this amount is deducted from the $48,500, the net saving to the city due to use of the coilfilter in lieu of digester and sludge beds was $46,070. When this saving plus interest is ammortized over a 20-year period at 4 per cent the yearly saving will be $3,388.90.

The cost of dewatering sludge was $5,597.78 for the first 12 months of

TABLE III.—Comparison of Bids for Digester Versus Coilfilter Construction

Bidder (No.)	Digester Base Bid ($)	Coilfilter Alternate Bid ($)	Apparent Saving ($)
1	383,600	319,400	66,200
2	406,900	333,800	73,100
3	367,900	325,900	42,000

record. If the initial saving of $3,388.90 per year were deducted from that amount, the resulting net cost of sludge dewatering would be $2,208.88. There appears to be no way of knowing exactly what the cost of sludge disposal would have been using a digester and sludge beds; however, it seems most probable that it would have been greater than the $2,200. If future operating costs are reduced the economies of the sludge filter should be more apparent.

Operator's Comment

The plant operator reports that the operation of a plant using a coilfilter presents few problems. When comparing the Union City sewage treatment plant with others, the operator was pleased to note that many of the problems confronting operators with digesters and sludge drying beds were not present in his plant.

Sludge was filtered regularly with no regard for weather. Seasonal variations in sewage pH, temperature, garbage content, detergents, and other digester troublemakers had relatively little effect on the sludge dewatering process. There is a noticeable odor from the sludge being filtered; however, it is an odor that disperses rapidly and is not perceptible outside the plant area.

During the months when a heavy lime dosage was being used, there was some difficulty with formation of scale in the filter vacuum and drain lines. This problem has been minimized with the reduced lime dosage. It is expected that the scale problem could be practically eliminated by the use of a high-grade high-calcium lime in low dosages.

All observations made during the first year of operation indicate that the coilfilter installation in Union City will be successful, both from a standpoint of savings in cost and in elimination of operational problems.

FEATURES OF A MECHANICAL SLUDGE CONCENTRATOR FOR DEWATERING SLUDGE*

By Edmund G. Smith

Development Department, The Ralph B. Carter Company, Hackensack, N. J.

This discussion will relate to the development of the Carter-EDCO Sludge Concentrator, a new method of dewatering sewage sludges. To appreciate fully the problems of sludge dewatering, the physical properties of sludge must be understood; particularly with respect to the behavior of sludge subjected to pressure during processes where the solid matter is separated from the fluid portion.

Nature of Sludges

In general, sewage sludge solids are mixtures of organic and inorganic matter, highly complex in nature, and composed of a large number of constituents which vary greatly with respect to concentration. The physical structure of these sludges is such that they can withstand very little mechanical pressure without breaking down. It is this characteristic that is of prime importance in dewatering processes.

Existing Mechanical Dewatering Methods

Sewage sludges may be dewatered by several mechanical processes, the most common are:

1. Gravity separation in sand beds where the action of gravity first acts on the fluid part of the sludge in

* Presented at the 1956 Annual Meeting, Kentucky-Tennessee Industrial Wastes and Sewage Works Assn.; Chattanooga, Tenn.; Sept. 17–19, 1956.

combination with the capillary action created by the sand. As the consistency of the sludge mass increases due to the removal of the water, the effect of gravity acts on the solid matter, compressing it to a moderate degree and freeing additional water. The remainder of the water is removed through evaporation.

2. Centrifugal separation where the effective weight of both the fluid and solid portions of the sludge are increased appreciably, and separation of the solid portion takes place either by deposition on a pervious medium, or by compression against an outer retaining wall.

3. Sludge compression where the sludge is placed in closed chambers having one or more surfaces provided with a pervious medium. Pressure is applied to reduce the volume of the chamber, as takes place in hydraulic presses or bag filters. In this action the pressure, while initially acting on the fluid portion, gradually takes effect on the solid matter as the sludge consistency increases and the voids between particles are closed, thus expelling more fluid through the pervious medium.

4. Vacuum or pressure filtration where the application of a fluid pressure, either air or liquid, forces the sludge against a pervious medium. The solid matter is retained on the surface of the medium, with the greater portion of the fluid passing through the medium to be carried away by suitable pipes or channels.

Effects of Pressure

In all mechanical dewatering processes involving the application of pressure, and where the solid matter being handled is structurally weak, a point of maximum pressure or "critical pressure" is reached above which the structure of the solid matter breaks down. The critical pressure point varies directly with the increase in concentration of the sludge being handled.

The bulk of the solid matter in sewage sludges consists of agglomerates or weak-structured cellular or gelatinous particles that break down at very low mechanical pressures. The addition of chemicals to these sludges will agglomerate the sludge particles and colloids, with the effect that the general particle size is increased and the deposition produced in a dewatering process will be more porous. Agglomeration by chemical treatment also reinforces the flocs formed, and raises the critical pressure point considerably. However, the pressure point is still not actually high enough to permit application of pressure in the degree used in dewatering equipment in use today, without varying amounts of difficulty.

The addition of pervious matter in the form of diatomaceous earth or fibrous material will tend to reinforce the depositions so that higher pressures can be used.

In mechanical dewatering devices that are to be operated continuously and where a deposition of sludge solids is to be removed cyclically from a pervious medium, as in rotary vacuum filters, filter presses, bag filters, or hydraulic presses, the deposition must be completely removed at the end of each cycle if the medium is to remain pervious.

When pressures above the critical point are used in producing a deposition, certain of the sludge solids will collapse and become enmeshed in the apertures of the medium irrespective of its construction. Subsequently, varying amounts of area of the medium become clogged with collapsed sludge particles to the extent that operation becomes impossible. Vacuum filters operating under these conditions must be cleaned periodically to restore porosity to the medium. The length of elapsed time between cleaning periods will vary greatly depending on the type and consistency of the sludge, the nature of the chemical treatment, the

filter pressure, and the type of filter medium.

Cleaning operations frequently involve considerable expense for labor and chemicals. In many instances considerable down time is involved, resulting in loss of production. In filters where provision is made for continuous sluicing of the medium with water, the cost of the power to supply the water becomes an important factor.

Range of Critical Pressures

The critical pressures are surprisingly low for all types of untreated sludge, being in the range of 1 to 1.5 in. of mercury. This is equivalent to approximately 1 to 1.5 ft. of water. Chemical agglomeration will increase the critical pressure to as high as 7 in. of mercury. This is still well below the pressure commonly used in continuous filter operations.

Carter-EDCO Sludge Concentrator

The solution to successful dewatering of sewage sludges can be found in acknowledging the difficult sludge characteristics and working with the sludge "as is," instead of trying to alter or overcome basic sludge characteristics. The Carter-EDCO Sludge Concentrator was developed with this express idea in mind. In this mechanism, dewatering actions occur at pressures well below the critical point. The dewatering is carried out in successive stages, with increasing pressure in each stage, so that heavy pressures are not used until the concentration has been brought up to the point where pressure may be employed without detrimental effects.

This sludge concentrator is composed of two separate components operating in series with each other under controlled conditions. The first compo-

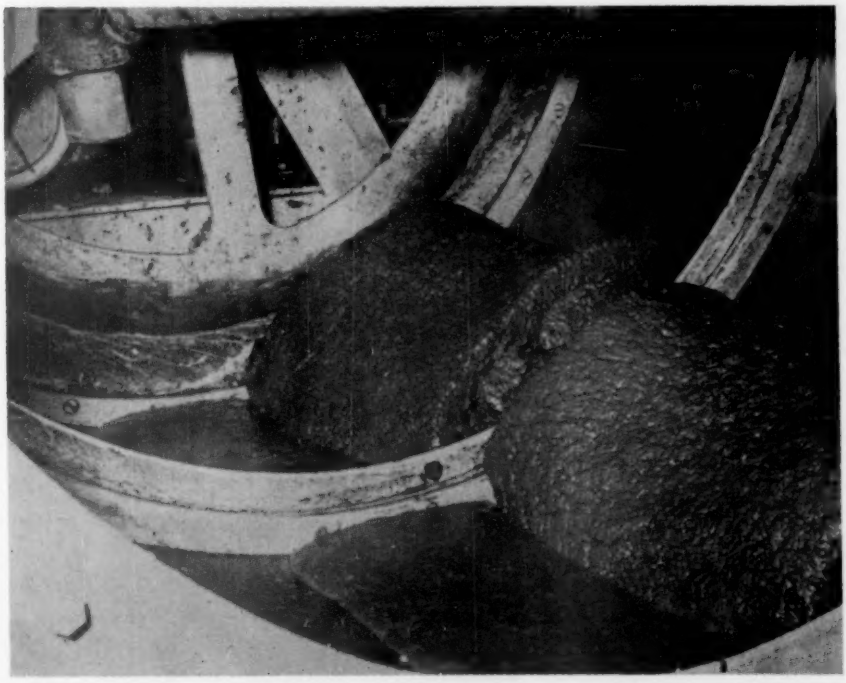


FIGURE 1.—Roto-Plug thickener. As the cylinder turns, the rolling plug of sludge squeezes moisture through the filter media which forms the cylinder wall.

nent is designated as a "Roto-Plug thickener" and the second is a "compression filter." The concentrator will operate on almost any material that has a reasonable degree of compressibility. In handling sludges that are noncompressible, small amounts of fibrous matter may be added to provide compressibility.

In the Roto-Plug thickener shown in Figure 1 the sludge, without having had any previous chemical treatment, enters continuously through the 1½-in. feed line at the open end of the cylinder, and distributes to both sides of the center flange. Here the first stage of dewatering begins. The sludge dewaters through the action of only a 1-

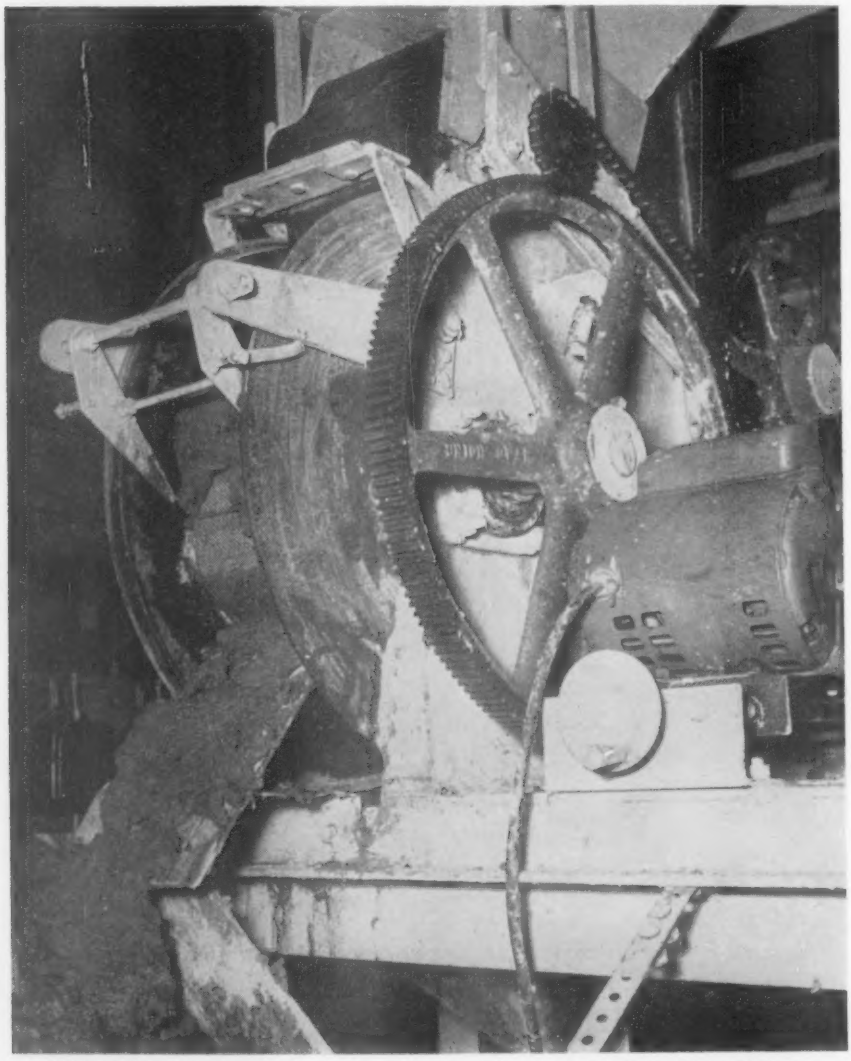


FIGURE 2.—Compression filter compresses sludge from the Roto-Plug thickener between two fluted rotors.

to 1½-in. head, far below the 12 to 18-in. equivalent head of water where danger of particle collapse begins. The sludge shown here is digested primary and activated sludge, received at 3.5 per cent solids.

When the unit is first placed in operation the sludge gathers in a small pool at the bottom of the cylinder formed by the filter medium, which is of 92-mesh nylon monofilament construction suspended only at the open edges. In this initial pool the sludge consistency is increased to 8 to 9 per cent through free-draining action only. This action takes place in a period of a few seconds. As the action continues, a small rolling plug of sludge rolls to the bottom of the cylinder and soon forms into a rolling mass essentially 8 in. thick by 16 in. long by 12 in. wide, as determined by the channel created by the center and end flanges. The rolling mass picks up the sludge deposition from the nylon medium, leaving the medium clean.

The critical pressure of the deposition formed in the initial pool at 8 to 9 per cent solids is approximately 24 in. of equivalent water head so that the weight of the 8-in. thick rolling mass does not exert excessive pressure.

When the rolling plug of sludge reaches the dimensions just mentioned, it begins to distend axially and part of it is cut away by the outer flange where it drops down to the compression filter. In commercial units, both ends of the Roto-Plug cylinder are open so that sludge discharges from both sides. The consistency of the rolling sludge mass as it leaves the Roto-Plug thickener is 12 per cent.

By controlling the various factors of design, it has been possible to make the plug form in a "sway back" shape which pulls in the trailing edge of the side face so that the inner faces of the flanges remain perfectly clean, eliminating any carry around of sludge. This also causes the material to discharge, for the most part, from the center of the plug which is slightly drier than the rest of the mass.

Dewatered sludge leaves the compression filter (Figure 2) in a sheet approximately ⅜ in. thick. Dewatering is accomplished by passing the sludge from the Roto-Plug thickener between two fluted rotors, driven in synchronism, where the sludge is compressed in contained pockets against the lower porous rotor, thereby expelling the liquor.

The commercial concentrator has two compression filters operating in series since the sludge cannot be completely dewatered in a single pass without again exceeding the critical pressures.

In the first filter the sludge enters at 12 per cent solids and is subjected to a pressure of only 10 p.s.i. The sludge leaves this stage at 20 per cent solids content and passes through the second-stage filter where it is subjected to a maximum pressure of 20 p.s.i., leaving with a 25 per cent solids content. Successive stages of dewatering can be added if a need arises for further reduction in water content. The sludge drops away from the final-stage filter and slides down a discharge chute. The sludge is in a form that can be shoveled or forked easily. It is also in a condition particularly suited for feeding to an incinerator or dryer. The sludge in the final dewatered form is mealy and does not tend to adhere to adjoining surfaces.

Power Requirements

The sludge concentrator requires a maximum of ⅓ h.p. per ton of sludge handled, including the power required to pump the sludge up to the unit.

Production Rates

The production rates of a standard four-element concentrator and the final solids content reached when handling the various sludges are given in Table I.

TABLE I.—Production Rates and Solids Content

Sludge	Rate (tons*/day)	Solids Content (%)
Primary	6.4	33
Primary and trickling filter	5.6	32
Digested primary	3.03	28
Digested primary and activated sludge	1.23	25
Digested primary and trickling filter	2.94	28
Activated sludge	1.87	24
Chemically precipitated	3.18	32

* Dry weight.

Advantages

The Roto-Plug thickener and compression filter afford several advantages. Most important is that conditioning chemicals are not necessary, thus making for simple and economical operation. Power consumption is low and the production rate is uniform, continuous, and fully automatic. The unit is well suited for locations where space is limited.

Conclusion

Consideration of the physical properties of sludge, particularly the behavior of the sludge under pressure, is essential to an understanding of sludge dewatering by mechanical means. Sludge is weak structurally, and the critical pressures at which the sludge breaks down are in the range of 1 to 1.5 ft. of water head.

Keeping the critical pressures low has resulted in the development of a new method of sludge dewatering which squeezes the water from the sludge.

INTERESTING EXTRACTS FROM OPERATION REPORTS

"It is not so much what we know as how we use what we know."—*Anon.*

Attention operators! It will be appreciated if copies of all annual reports of both large and small sewage and industrial waste treatment plants are sent to the Federation office for abstracting in this section of the Journal. Please direct annual reports to: The Operator's Corner, Federation of Sewage and Industrial Wastes Associations, 4435 Wisconsin Ave., N.W., Washington 16, D. C.

First and Second Annual Reports of the Walla Walla, Wash., Sewage Treatment Plant

By Edgar R. Lynd, *Superintendent*

Original sewage treatment facilities for the City of Walla Walla, Wash., were constructed in 1926. The plant was enlarged to a capacity of 15 m.g.d., at a cost of $600,000, and placed in operation in May, 1954. The population served is estimated to be 25,400.

Editor's Note—Superintendent Lynd has resigned to further his study of sanitary engineering at Oregon State College, Corvallis, Ore.

The annual reports cover the periods from May 1 through April 31, for the 1954–55 and 1955–56 operating years.

In addition to the treatment facilities constructed and operated by the city, there is a small treatment plant which was constructed at the city treatment plant site by the federal government in 1941 to handle the flow from the Veterans' Administration Hospital. This plant was acquired by the city

and operated until May, 1954, when it was placed on a standby basis.

Treatment facilities consist of grit removal, solids comminution, preaeration, primary clarification, first-stage filtration, intermediate clarification, second-stage filtration, final clarification and chlorination. One primary and two secondary digesters make up the digestion system. Sludge is dried on four asphalt-paved sludge beds. The plant effluent is used by two irrigation districts.

The raw sewage flows through a 27-in. clay line under a head of approximately 15 ft. At peak flows the pressure head increases to the point where the joint compound will give way in one or more joints. Repair work necessitates the use of the industrial waste line, by-passing the raw sewage line. Average flow has been 5.4 m.g.d. in 1954–55 and 6.4 in 1955–56. Dry weather flows vary from a peak of about 7.5 m.g.d. to a low of 4.0 m.g.d. Maximum wet-weather flows reach a high of 15 m.g.d.

Grit Removal

Grit is removed by aeration in the main grit channel with an air supply of 100 c.f.m. at 6.5 p.s.i. The grit is collected in two hoppers and elevated by an air lift to a grit washer and storage hopper. The wash water is returned to the raw sewage flow. The grit chamber has a hydraulic capacity of 8.5 m.g.d. Excess flow is diverted to the comminutor through a slide gate fitted with an adjustable weir.

Fouling of the grit air lift with rags and debris was nearly eliminated by the installation of a plug valve on each lift. This permits shutting off the flow to the storage hopper and, by opening the air control valve, air is forced out of the intake of the air lift, thus providing an effective means of back flushing.

Close control of the air output from the diffuser tubes is essential to obtain a good quality grit, free of organic solids.

Comminutor

Flows in excess of the 10.5-m.g.d. capacity of the comminutor overflow through a bar screen. Trash collecting on the screen must be removed periodically and temporarily stored on the operating deck.

After two years of operation the bottom two cutting combs were replaced and new teeth installed. The teeth opposite the two upper combs were sharpened and reinstalled.

Preaeration

Preaeration of the sewage usually begins in May, when the D.O. content of the sewage decreases, and continues for about six months. Diffuser tubes are cleaned in place regularly every two weeks. Equipment has been installed for periodic tube cleaning with a detergent in a jet cleaner located in the "government plant."

Clarifiers

Clarifiers are of the straight-line type and provide for the continuous removal of sludge. Two new units were constructed for primary settling and one unit for final settling. The two intermediate and two final clarifiers were modified from existing tanks.

Scum is removed from the primary unit only. If an unusual quantity of grease is present, raw or digested sludge may be mixed with the scum to facilitate pumping. Grease accumulations can build up in the suction line, causing a blockage. Hot digester supernatant, forced through the line about once each month, has a scouring action and has reduced grease stoppages to a minimum.

An excavation cave-in into an open sewer line, and the subsequent flushing of clay to the treatment plant by the construction workers, resulted in 15 to 20 yd. of clay entering the plant. Three primary clarifier cross flights and one side collector were broken and sludge lines were plugged.

In cases of extreme emergency, the

final clarifiers can be used as primary settling tanks, thus preventing any necessity for by-passing raw sewage. To provide sufficient sludge pumping capacity to remove sludge in case of emergency use, an additional sludge pump was installed to serve these clarifiers.

Drains were installed from each final clarifier to the outfall to facilitate dewatering the tanks.

Filters

The first-stage or roughing filter is 145 ft. in diameter and has a capacity of 15 m.g.d. Recirculation of 7.5 m.g.d. is possible. The rate of recirculation is determined by the dissolved oxygen present in the primary effluent and the ability of the filter to make a satisfactory recovery. Recirculation is discontinued in the winter months and during storm flows.

A 220-ft. square standard-rate filter, with dosing syphon and 297 nozzles, handles 7.5 m.g.d. Flows in excess of this, overflow directly from the roughing filter to the final clarifier.

Digestion

The sewage solids are handled in one primary floating-cover digester (new) and two secondary fixed-cover digesters (old). During the initial operating period the seed sludge was lost and the supernatant screen was damaged beyond repair. The screen was replaced with an open pipe and the supernatant re-piped to the old digesters, which were converted from sludge storage to secondary digestion.

Recirculation of the primary sludge through a heat exchanger occurs when raw sludge is added to the digester. Digester gas is used for sludge heating and plant heating purposes. Digester temperature has been maintained at 96° F., even during sub-zero weather. The use of auxiliary fuel for digester heating has not been necessary.

Digested sludge is dried on four asphalt-paved drying beds (THIS JOURNAL, **28**, 5, 697; May, 1956). Drying time varies from 35 to 45 days, and power equipment is used exclusively for cleaning the beds.

Industrial Wastes

Three large food processing plants (canneries) contributed most of the B.O.D. load received at the plant. During the canning season this flow amounts to about 4 m.g.d. To reduce this load, a separate line was constructed to each cannery in 1952. The canneries screen all waste with a 40-mesh screen and maintain the pH of the waste at 7.0. This waste water is piped to a point below the sewage treatment plant site, where it is delivered to an irrigation district. The "industrial waste" line can discharge to the treatment plant and is used when the canneries are not operating, to carry excess storm flow.

Initially, considerable amounts of oil and solvent were received at the treatment plant. A letter, explaining the hazards of these wastes, was sent to the local business firms and good cooperation in the control of these wastes has been experienced.

Plant and Grounds

During the first year of operation many improvements were made to the plant grounds. Concrete sidewalks and paved areas were provided. Adequate lighting was installed to aid the night operators in the performance of their duties and as a safety feature. All of the plant property between the plant structures and the receiving stream (Mill Creek) was landscaped. This required seeding 2½ acres to grass, which brought the total lawn area to 3¼ acres. In addition, shrubs and trees were planted around the buildings. Additional water taps have been provided for an overhead sprinkling system. The remainder of the 12-acre plant site has been leased for planting to a cover crop.

Operating data for the first two years of operation are given in Table I.

TABLE I.—Summary of Operating Data for the Walla Walla, Wash., Sewage Treatment Plant for the Two-Year Period, May 1, 1954 to April 30, 1956

Item	Average 1954–55	Average 1955–56
Population	25,400	25,400
Flow (m.g.d.)	5.4	6.4
Suspended solids (p.p.m.):		
Raw	203	131
Primary	51	46
Intermediate	39	33
Final	23	18
Reduction (%)	88	86
B.O.D. (p.p.m.):		
Raw	129	143
Primary	84	81
Final	19	21
Reduction (%)	85	85
Dissolved oxygen, effl. (p.p.m.)	8.8	8.8
Chlorine:		
Total (lb.)	2,568	2,450
Residual (p.p.m.)	0.2	0.25
Raw sludge:		
Volume pumped (g.p.d.)	19,966	14,738
Solids (%)	—	5.5
Volatile (%)	—	71.7
pH	6.6	7.2
Temperature (° F.)	91	97
Digested sludge:		
Solids (%)	—	7.9
Volatile (%)	—	44.5
Gas production:		
Total (mil. cu. ft.)	0.770	1.126
Daily (cu. ft.)	25,440	36,915
Operating costs ($):		
Salaries	19,399.44	20,377.80
Maintenance and supplies	2,653.20	2,302.20
Power	5,139.00	4,764.96
Chlorine	2,216.52	2,123.52
Total	29,408.16	29,568.60
Per mil. gal.	15.15	12.96

LOW-COST WATER BATH INCUBATOR

Operators interested in running B.O.D. determinations, but lacking the financial means to purchase an expensive incubator, will be interested in the success Superintendent William E. Loftin had at the Gresham Sewage Treatment Works, Troutdale, Ore. Superintendent Loftin constructed his own water bath incubator more than a year ago at a cost of $14.00 and about 8 hr. of labor.

The basic requirement of the water bath incubator is to have a constant water supply at a temperature under 20° C. The objective is to control the bath temperature at 20° C. by heating the cold water. Since there is no refrigeration, a water supply warmer than 20° C. cannot be used; therefore, the water temperature must be checked carefully. If service is from a water utility, inquiry can be made as to the maximum water temperature to be expected during the year. If it exceeds 20° C. during certain months, the incubator should not be used unless some arrangement can be made to cool the water. A few coils

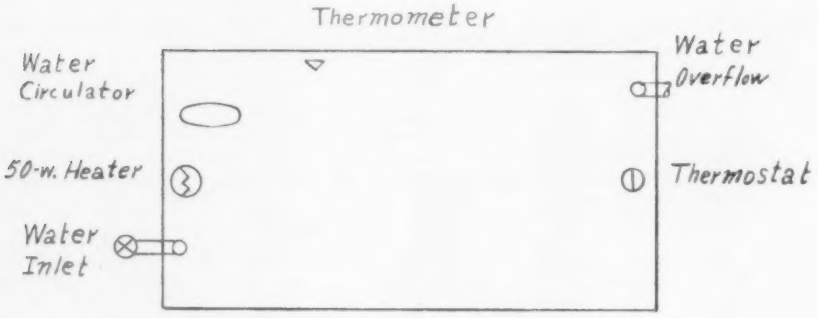


FIGURE 1.—Low-cost water bath incubator.

of copper tubing run through a refrigerator should reduce the inlet water below 20° C.

The small tank, 20 in. by 14 in. and 12 in. deep, was made from galvanized sheet metal. A small water control valve was installed at one end of the tank and a water overflow line at the other end.

Other units needed were a fish aquarium thermostat and a heater element. For the size tank mentioned, a 50-w. heater was adequate. If the water temperature is low a larger heater may be necessary. The thermostat is wired into the heater circuit to control the heater.

A used electric fan motor or refrigerator cooling fan motor, of about 1/30 h.p., was needed for circulation purposes. A shaft was fitted to the motor and a small impeller was soldered to the end. This unit provided good water circulation in the tank and was wired for continuous operation. Power consumption of this small motor is low.

Arrangement of the unit is shown in Figure 1. The tank can be equipped with a metal or insulated cover to help maintain a uniform water temperature.

A certain amount of trial-and-error adjusting is necessary to obtain the best setting for water inflow in order to maintain the bath at 20° C. A supply that has a constant temperature, such as ground water, will not have the temperature fluctuations such as with a surface water supply, thereby reducing the flow adjustments to a minimum. Superintendent Loftin has had considerable success in maintaining his incubator at 20° C.

Design variations and refinements to this water bath incubator will come quickly to the operator who gives some thought to the construction of his own unit.

TIPS AND QUIPS

Pink Effluent

Raw sewage went into the new sewage disposal system at Petersburg, Va., and out came pink effluent. The unusual color was due to rouge used in lens grinding by a local optical goods manufacturer.

Plastic Pipe Extruder

A patent was obtained recently on a plastic pipe extruder, which when mounted on a tractor extrudes pipe continuously as the tractor moves forward. Seamless, jointless pipe can be laid at a speed of several miles per hour.

Safety Begins with You

More than 75 per cent of all accidents are caused by unsafe actions (human failure), and only 20 per cent are the results of unsafe conditions. So—

1. Use safety devices.
2. Don't operate equipment at unsafe speeds.
3. Get instruction and authority before you use new equipment.
4. Don't take chances.
5. Lift properly heavy loads and objects.
6. Pick up tools.
7. Keep floors clean and dry.
8. Report unsafe working conditions.

Sludge Disposal

A recent release, "The Complete Disposal of Sewage Sludges," is an attractive brochure that describes approaches and developments in the incineration of sewage sludges, as viewed by the William E. Farrer Co., Birmingham, England.

Copies of the brochure may also be obtained from Kenny Consolidated Engineering Industries, Ltd., 58 Wellington St., East, Toronto, Canada.

$99 Million Per Year

The Municipal Finance Officers' Association, in a recent study, found that some 300 cities were collecting $40 million per year ($2.84 per capita) from refuse service charges and $99 million per year ($3.25 per capita) from sewer rental charges.

Objectionable Design Features

Operating personnel will fuss about this feature or that in their plant, even when the plant is new, but it is not often that we can obtain a uniformity of opinion on specific design features that are objectionable and, therefore, need improvement. The consensus of opinion of a meeting of operators in southern Illinois, held last fall, was that the following improvements were needed *:

1. More careful investigation of needed pump capacity in lift stations.
2. Better control of sludge withdrawal from settling tanks, including more rapid adjustment of telescoping valves. Shelter for the operator who must remain at the sludge wells while withdrawing sludge.
3. Adequate system of walks.
4. Elimination of maintenance problems created by steep embankments.
5. Consultation by design engineers with superintendents of sewage works.
6. Better ventilation of structures.
7. Inclusion of fencing around plant grounds, and railings around tanks.
8. Elimination of easily-broken windows in outlying lift stations.

The need for some of these recommendations will be felt particularly by operators of old treatment plants. However, all operators will appreciate one or two of these recommendations or think of others—or is there an operator with a perfect plant?

Manhole Styles

The city engineering department of Miami, Fla., has capitulated to women's fashions and ordered 500 new manhole covers with holes too small to catch the heels of feminine shoes. New covers will have holes 5/8 in. in diameter, compared with 1 in. in the old covers.

The decision to buy new covers followed a lawsuit brought by a woman who said she fell when her heel caught in one of the old style covers.

* From *The Digester*, Illinois Dept. of Public Health (Nov., 1956).

News and Notes

Of Persons and Activities in the Field of Hydrowastes

Dr. H. Heukelekian was recently appointed Chairman, Department of Sanitation, Rutgers University, succeeding **Dr. Harold E. Orford,** who will continue with research and teaching activities.

W. A. Hasfurther, a Sanitary Engineer with the Illinois Department of Health for many years, has resigned to accept the position of Deputy Engineer, Anne Arundel County Sanitary Commission, Glen Burnie, Md.

Walter A. Harris has been transferred from B-I-F Industries of Canada, Ltd., to the home office of B-I-F Industries in Providence, R. I., where he assumes new duties.

George M. Hite and **M. D. R. Riddell,** members of the staff of Greeley and Hansen, Engineers, Chicago, Ill., have been admitted to partnership in the firm.

George M. Darby has retired as Director of the Westport Mill, Dorr-Oliver Laboratories, where he was associated with research and development work for 37 years.

Dr. John C. Geyer has been named Chairman of the Department of Sanitary Engineering, Johns Hopkins University, succeeding **Dr. Abel Wolman,** who will remain on the faculty.

Charles T. Walsh has been admitted to partnership in Bowe, Albertson and Associates, Engineers, New York City.

Charles F. Niles, Jr., Superintendent of sewage treatment, Muncie, Ind., has joined the engineering firm of Henry B. Steeg and Associates, Indianapolis, Ind.

Charles-Edward Amory Winslow, Professor Emeritus of Public Health, Yale University School of Medicine, died recently at the age of 80. He was active in the initial development of *Standard Methods* and a dean in the field of public health.

The appointment of **F. C. Heinz,** vice-president in charge of industrial relations for H. J. Heinz Co., by President Eisenhower, brings to full strength the newly created nine-member water pollution control advisory board of the Public Health Service.

Charles G. Richardson, retired vice-president of Builders-Providence, Inc., Division of B-I-F Industries, died recently. A member of the New England Member Association and Life Member of the American Water Works Association, he served for a number of years on the board of governors, Water and Sewage Works Manufacturers Association.

Academic halls beckoned **Gordon E. Mau,** who is presently working on completion of his Ph.D. at the University of Iowa. Mau recently resigned as Chief, Water Pollution Control Section, Kansas State Board of Health, to accept a position with the Ediger Engineering Company, Wichita, Kans.

Charles A. Haskins, head of Haskins, Riddle and Sharp, Consulting Engineers, Kansas City, Mo., died recently. Active in Federation activities, he was well-known as a consulting sanitary engineer.

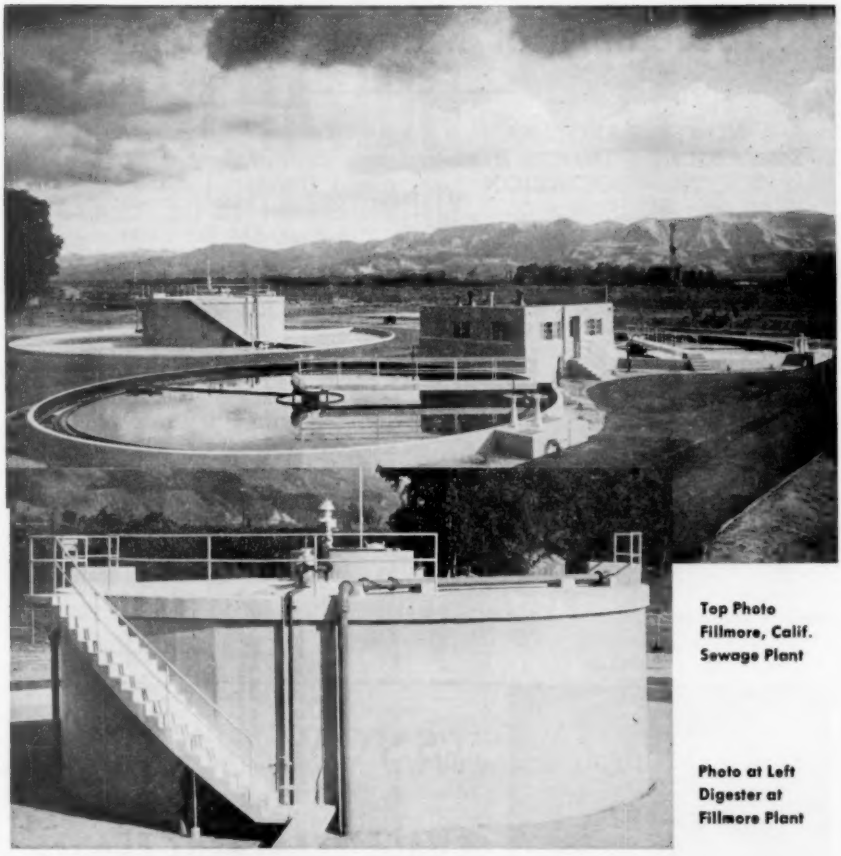
Recently appointed to the Public Health Service national advisory committee on public health training was **Dr. Rolf Eliassen,** Massachusetts Institute of Technology.

Robert R. Harris, has been named chief of the sewage treatment plant construction program, U. S. Public Health Service, Washington, D. C.

Thomas R. Glenn, Jr., Associate Professor, Civil Engineering Department, Rutgers University, has been appointed Assistant Chief Engineer of the Interstate Sanitation Commission, which is directed by **Seth G. Hess,** Director and Chief Engineer.

H. M. Gifft, Professor of Civil Engineering, Cornell University, died recently. He was Dean-elect of the University faculty.

A Member Association to serve the interests of sewage and industrial wastes personnel in Utah appears to be near reality. **William T. South,** General Manager, Salt Lake City Sanitation District, has been instrumental in the early planning.



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NORTH CAROLINA SEWAGE AND INDUSTRIAL WASTE ASSOCIATION

The 1956 Annual Convention of the North Carolina Sewage and Industrial Waste Association was held jointly with the North Carolina Section, AWWA, at Charlotte, N. C., on November 12–14, 1956.

The technical program featured papers of interest to both water and sewage works personnel as follows:

"Your Responsibilities in Corrosion Prevention," by T. F. Altizer, President, Steel & Tank Service Co., Charlotte.

"Use of Water Under North Carolina Statutes," Claude L. Love, Assistant Attorney General, Raleigh.

"Treatment of Fringe Areas as Regards Utilities," by G. H. Esser, Assistant Director, Institute of Government, Chapel Hill.

"Federal Aid for Pollution Abatement," by E. C. Hubbard, Executive Secretary, State Stream Sanitation Committee, Raleigh.

A panel discussion of operators' problems covered the subjects of public service employee classification, small town operating problems, and progress on regional schools for sewage works operators.

One of the social highlights of the meeting was a dinner given on behalf of the Charlotte Water Department. At the annual banquet awards were

(*Continued on page 208a*)

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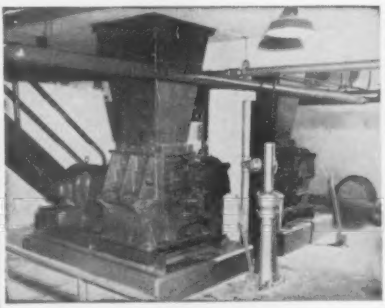

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The following officers were elected for 1956–57:

Chairman: Carl W. Mengel, Raleigh.
Vice-Chairman: William F. Stokes, Hendersonville.
Secretary-Treasurer: W. E. Long, Jr., Raleigh.

W. E. Long, Jr.,
Secretary-Treasurer

IOWA SEWAGE WORKS ASSOCIATION

The 38th Annual Meeting of the Iowa Sewage and Industrial Wastes Association was held at Clear Lake, Iowa, September 12–14, 1956. The 1956 program again featured two panel discussions—one covered the subject of sewage treatment from initial idea to final operation and the other featured discussions on sludge drying, federal stream pollution control, industrial research and pollution control, and operator self-helps. An operator's breakfast and discussion concluded the program.

The presence of Professor Adolf Cerny, on a visit from Vienna, Austria, lent an international flavor to the meeting.

Officers were elected for 1956–57 as follows:

President: Karl Hirlinger, Ottumwa.
Vice-President: H. S. Smith, Muscatine.
FSIWA Director: Harris F. Seidel, Ames.
Secretary-Treasurer: L. F. Skorczeski, Marshalltown.

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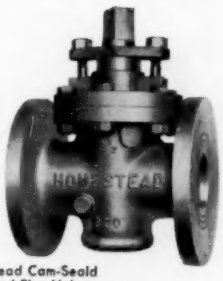

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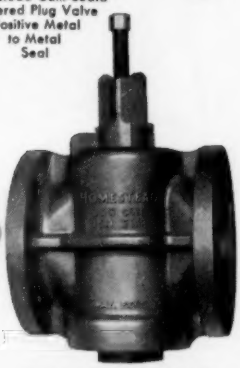

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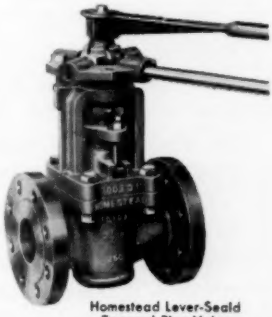

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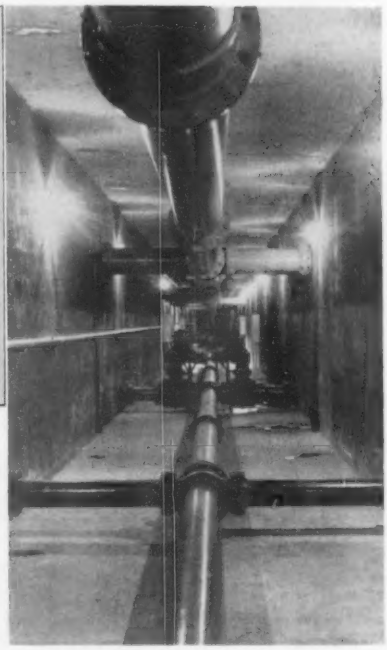

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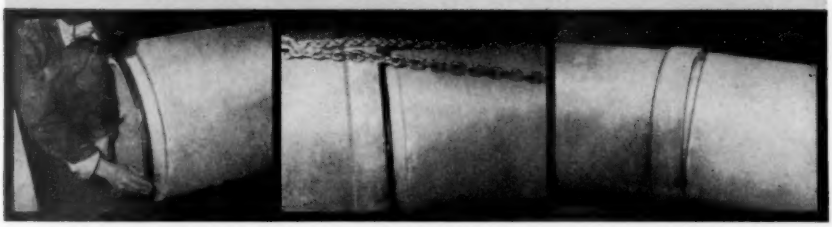

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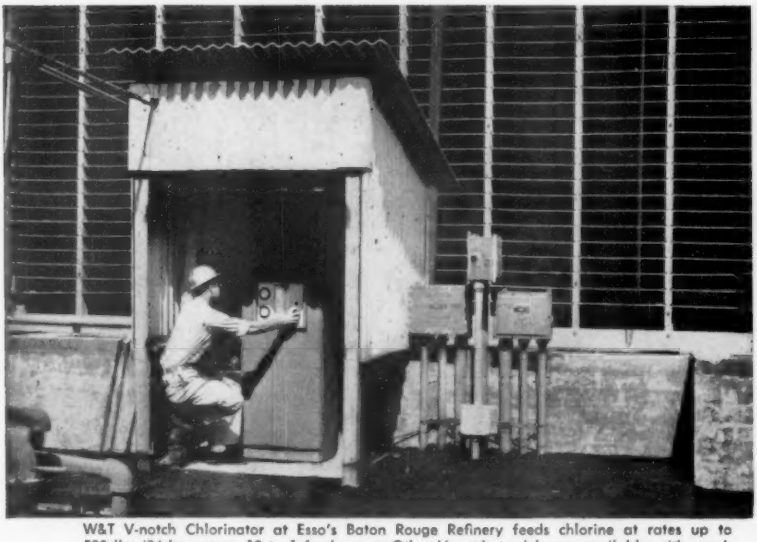

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